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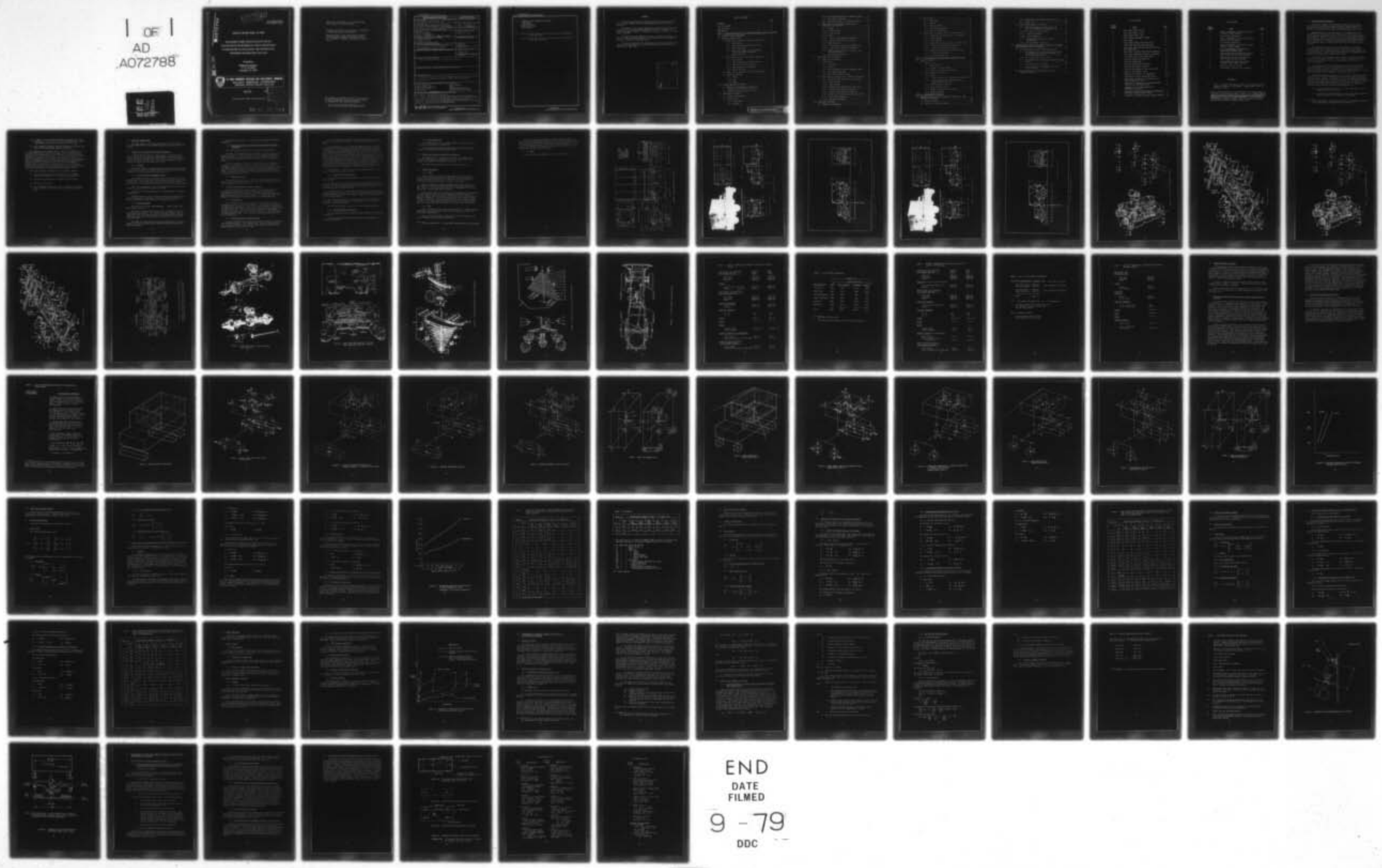

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CONTRACT REPORT ARBRL-CR-00399

PRELIMINARY TARGET DESCRIPTION DATA FOR THE CALCULATION OF THE RESPONSE OF A TRUCK-SHELTER-RACK SYSTEM EXPOSED TO A BLAST WAVE, AND PROPOSED TEST PROCEDURES FOR OBTAINING SUCH DATA

Prepared by

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BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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18. SUPPLEMENTARY NOTES

This report supports DNA Subtask V99QAXNB005, Land Based Weapons Systems Vulnerability and Hardening, Work Unit Code 05, Military Equipment vulnerability.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

VEHICLE DESCRIPTION
VEHICLE DYNAMIC MODELING
VEHICLE DATA INPUT
LEAF SPRINGS
SHOCK ABSORBERS
TIRES
TEST PROCEDURES FOR DATA
ELECTRONIC EQUIPMENT SHELTER

(Continued)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report is divided into three parts.

Part I: Preliminary target description data for the development of a matrix equation of motion of a dynamic model for the total truck-shelter-rack system in response to a blast wave under various ground conditions are presented. Also presented are recommendations for the development of the model as well as constraints on some of the data-input.

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19. COMMAND CONTROL COMMUNICATION SYSTEMS
DICE THROW
BLAST RESPONSE
STRUCTURAL DYNAMICS
BLAST LOADING

continued

20. Part II: Issues and needs are listed for analysis and testing to obtain input data.

Part III: Preliminary test plans are presented for obtaining the input data required.

FOREWORD

This work was performed for Ballistic Research Laboratories under Contract Number DAAD05-74-C-0754 by Radkowski Associates, Riverside, California.

The authors of this report appreciate the discussions and technical suggestions for analysis and testing from Mr. Noel H. Ethridge (the technical manager for BRL), Dr. William J. Schuman Jr., and Dr. W. Donald Allison from BRL.

The authors wish to thank Drs. Yau Wu, E. Salvadore Criscione, and Norman P. Hobbs from Kaman-Avidyne on the discussion of their dynamics modeling and format for the input data.

The authors appreciate the cooperation that they have received from numerous government agencies, private corporations, and individuals in obtaining the input data.

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REFERENCES

1. Wu, Y., A Dynamic Mathematical Model of a Truck-Shelter-Rack System in Response to a Blast Wave. Kaman-Avidyne, KATR-113, November 1, 1974.

(Note: A later description of the code written by Kaman-Avidyne is contained in the report by Norman P. Hobbs, et al., TRUCK-A Digital Computer Program for Calculating the Response of Army Vehicles to Blast Waves, Contract Report ARBRL-CR-00369, U. S. Army Armament Research and Development Command, Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, April, 1978)

1.0 INTRODUCTION AND BACKGROUND

The dynamic response of an equipment (shelter) mounted truck subjected to a blast from a detonated weapon is being studied by the Ballistic Research Laboratory (BRL) and Kaman-Avidyne (Reference 1). Of particular concern in the study is the overturning of the vehicle.

Kaman-Avidyne models the gross motion of a parked vehicle by considering the interaction of the vehicle and side-on blast as a non-linear dampened spring-mass system. The motion of the system depends on the aerodynamic moment due to the blast, the restoring moments from the inertia system, and the friction forces from the wheel-ground sliding-motion interaction. In doing this, Kaman-Avidyne considers the vehicle to be symmetric about the fore and aft vertical center plane of the vehicle.

The "Data-Input" aspects of the dynamic model of the parked vehicle subject to the side-on blast are considered in this report. The data inputs are the geometry, mass, spring, and damping characteristics of the vehicle. Also, based on the data-input, recommendations are presented for modifying the Kaman-Avidyne model.

The details of the geometry, mass, spring, and damping characteristics of the equipment shelter and its internal components, as well as the tie-down tension wire, were not available at the time of this report's preparation.

The terrain and other related factors are not specified because they are dependent on the actual geographical site of the vehicle and the blast-vehicle interaction. However, for the purposes of this report the ground slope is assumed to be zero and some preliminary information is presented for the mechanical properties of the soil.

The detailed weight distributions of the vehicles apparently are not available and it would be prohibitive* to derive them under the present scope of effort. However, it appears that it is not immediately necessary to obtain the weight of each structural component as the variances between the actual detailed weight distributions and the data presented in this report are less than the variances of other factors. Circumstances initiating these variances in weight determination are:

(1) a spring constant variance of up to 25%, depending on such factors as the vehicle's age;

(2) a variance in load distribution on each wheel between different parked positions due to binding of the bearings;

* Cost of obtaining a detailed list of parts from USAMCTA-RB computer for a M35A2 vehicle is $12,000.00 (Mr. John Pace).

(3) a change of load distribution between the wheels due to the attachment of the load on the truck bed affecting the movement (even though it would be a small amount) of the load;

(4) and a geometric asymmetry and mass distribution variance from that of the Kaman-Avidyne symmetry assumptions.

The asymmetrics are primarily due to basic design features, e.g. the drive train and fuel tank positionings. This is illustrated by the M715 (1¼) ton vehicle which has a fuel tank on the left and a dual unsymmetric fore and aft drive train. This 1¼ ton vehicle, fully loaded with full fuel tank but less the operators weight, will have, at the curb, an approximate 9 to 11% load variation between the two front wheels. Likewise, the center of gravity of the vehicle is approximately one (1) inch to the left of the fore and aft center line of the vehicle. (Consequently, for the purposes of determining the lateral (side-on) response of the vehicle, it is recommended that a data input sensitivity study be performed using the damped spring-mass dynamic model.)

This report presents information in the following sequence:

(a) Geometrical descriptions of the M35A2, M715, and M38A1 vehicles including some of the geometrical asymmetries;

(b) A modified (by geometrical schematics) dynamic model;

(c) Data-input information;

(d) And, recommended testing for either refinement of available data, determining *unavailable* data, or qualifying presented data.

2.0 VEHICLES' DESCRIPTIONS

The M35A2 (Figure 1) less the S280 shelter, the M715 (Figure 2) with the S250/G shelter, and the M38A1 (Figure 3) are described in this section.

2.1 M35A2 Vehicle's Reduction into Major Components

The M35A2 vehicle (Figure 1) with shelters can be reduced into shelter (with racks and electronic componentry), truck body (frame, engine, and cab), front axle with wheels and bogie (two axles with two sets of dual wheels on each axle). These major components are tied together by spring and shock absorbing systems.

2.1.1 Shelter

The shelter S280 is in design modification and no attempt is made in this report to define or describe the data for either the rack-shelter interaction or the shelter-vehicle frame interaction.

2.1.2 Spring and Shock Absorbing Systems

Even though there are two springs of the 10-leaf type between the frame and the bogie, there are no shock absorbers between the rear bogie and the frame. (The torque rods tying the two rear axles together in the bogie act as shock absorbers only between the two axles and the frame.)

There are two springs of the 12-leaf type and two shock absorbers between the front axle and the frame of the body.

The 9:00-20 tires interacting with the ground behave in a damped-spring manner.

The S280 shelter is now in a design process and is expected to be tied by either wires or fastened or both to the body of the vehicle possibly through some shock absorbing and spring-like system.

2.1.3 Body Description

The body has three major sub-components: engine, frame (with power train), and cab.

The engine is a multi-fuel engine and it is mounted to the frame as illustrated in Figure 4. It is easily seen from Figure 4 that no significant shock or spring-like action occurs between the two masses (frame and engine) other than through the mechanical behavior of the frame and engine.

The frame less power train is described schematically in Figure 5. Figure 6 presents an overlay of the frame over the power train and the wheel-axle systems.

The exterior of the cab has already been schematically presented in Figure 1.

2.1.4 Axles, Axle Frames, and Corresponding Spring Suspension Assemblies

The front and rear axle assemblies are described in Figure 7.

The front 12-leaf spring and axle assemblies installed are seen at the top of Figure 8. (Note the location of the spring, approximately halfway between tires and center plane, and the asymmetry of the front axle.) The front suspension and spring assemblies are illustrated in Figure 9.

The rear suspension of 10-leaf spring assemblies are illustrated in Figure 10. Although not shown in Figure 10, the two rear axle assemblies (Figure 8) are tied to the center section by torque rods and the center section is tied to the spring. The spring is then tied to the frame. (It is interesting to note that the spring orientation in the front suspension assembly (Figure 9) is different from that of the rear suspension assembly (Figure 10).)

2.1.5 Wheels and Tires

The inflated tires (Figure 1) perform a damped-spring-like function under a lateral and normal dynamic load. The front and rear tires are size 9:00-20 and are under 45 psi.

2.2 M715 Vehicle Reduction into Major Components

The M715 vehicle described in Figure 2 can be reduced into the following major components: shelter (with racks and electronic componentry); truck body (frame and drive train, engine, and cab); front axle with wheels; and rear axle with wheels. The components, like the M35A2, are tied together by shock absorbing and spring assemblies.

2.2.1 S250 Shelter

The M715 Cargo Truck can accommodate the S250/G type Electrical Equipment Shelter as illustrated in Figure 2. The shelter is constructed of aluminum and is designed to house various communication configurations. It weighs 630 pounds and has a payload of 1,900 pounds when transported by the M715 cargo truck. The shelter is RFI shielded and incorporates a combination sling for left end tie down to the vehicle. The S250 shelter is being analyzed by BRL. It is currently being design-modified and no data are available.

2.2.2 Shock Absorbing and Spring Systems

The M715 vehicle shock absorbing and spring assemblies are analogous to the M35A2 assemblies. The exceptions are: There is only one rear axle (instead of two) and there are two shock absorbers and two springs mounted between the rear axle and frame.

The shock absorbing and spring systems between the frame and the shelter (as well as those internal to the shelter) are now being defined by BRL.

The characteristics of the spring and damping systems (including the tires) are defined in terms of force-deflection and force-velocity relationships. It is well known that these relationships are sensitive to environmental and assembly configurations. Even in the linear range of the force-deflection relationship ($F = Kd$), where F, K, and d are the applied force, spring constant, and deflection, respectively, the spring constant could vary on the order of 25% from a new off-the-shelf position to an installed position on the vehicle. Also, this spring constant for the linear spring range could vary because of either the lubricant or dust or both seeping between the leaves of the leaf springs, or the age degeneration of the spring or other similar occurences. Likewise, the spring constant for the spring-shock absorbing characteristics of the inflated tires could vary because of tire pressure, age of tire, etc..

Analagously, as in the spring system, the damping system's force-velocity relationships could also vary.

2.2.3 Body and Axles Descriptions

The body has three major sub-components: engine; frame with power train; and cab.

The exterior of the cab and the engine are illustrated in Figure 2. The frame with drive train and the front and rear axles are illustrated in Figure 11. The transmission, with a 300 pound-foot rating, is a four-speed synchromesh type with cane shift.

The transfer case is a two-speed, all helical gear, drop gear box located remotely just to the rear of the transmission. As in a conventional four-wheel drive vehicle, this transmits power from the transmission to all four driving wheels.

The front driving axle is a heavy duty model of the conventional solid type. Heavy-duty spindles are combined with sealed steering knuckles to achieve durability.

The rear driving axle is also of the solid full-floating type.

2.2.4 Spring Suspension Assemblies

The front-spring and axle installation and assemblies are presented in Figure 11.

The rear suspension and spring installation and assemblies are presented in Figure 11.

2.2.5 Wheels and Tires

The inflated tires are size 9:00-16 under 25 psi and 45 psi for the front and rear wheels, respectively.

The inflated tires perform a damped spring-like function under normal to the ground and lateral dynamic loads.

2.3 M38A1 Vehicle Reduction into Major Components

The M38A1 vehicle is analogous to the M715. The M38A1 vehicle does not accommodate an equipment shelter. The M38A1 vehicle and component descriptions are similar to the M715.

The front and rear tires are size 7:00-16 under 25 psi.

2.4 Weight Distribution

2.4.1 M35A2

Table 1 presents the vehicle characteristics with dimensions, and the weight distribution over the two axles. The positions of the center of gravity of the vehicle for both the loaded and unloaded conditions are presented in Table 1 as well as in Figure 1.

Table 2* illustrates a typical weight variance that may occur in the M35A2 type vehicle as measured by Technical Operating Procedure, MTP 2-2-801. It is seen that the variance is approximately 5% or less between the left and right wheel positions.

Factors that could cause variance in the unsymmetric load condition are quite apparent from the lack of geometrical symmetry about the vehicle's center plane of the axles, drive train, etc. as illustrated in Figures 1 through 10. It is also known that the load variance between the wheels could vary in driving the vehicle from one to another parked position. This could result from such instances as the binding of the gears, a change in the spring constant, or a slight shift in the load.

2.4.2 M715

Table 3 presents the M715 vehicle characteristics. Table 3 includes dimensions, weight distribution, and center of gravity for loaded and other related conditions.

Figure 2 likewise presents diagrams that give the dimensions and center of gravity of the vehicle less shelter.

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* Private communication: R. Wilke MTD, TECOM Aberdeen Proving Grounds.

There is an apparent variance in vehicle weight and center of gravity based on such factors as those presented for the M35A2 vehicle. Table 4 presents data for the M715 vehicle weighed and measured in 1967 at Aberdeen Proving Grounds. It is quite obvious that there is a variance in the symmetry of the vehicle's weight distribution by 9 to 11% between the left and right front wheels.

2.4.3 M38A1

Table 5 presents the M38A1 vehicle's characteristics.

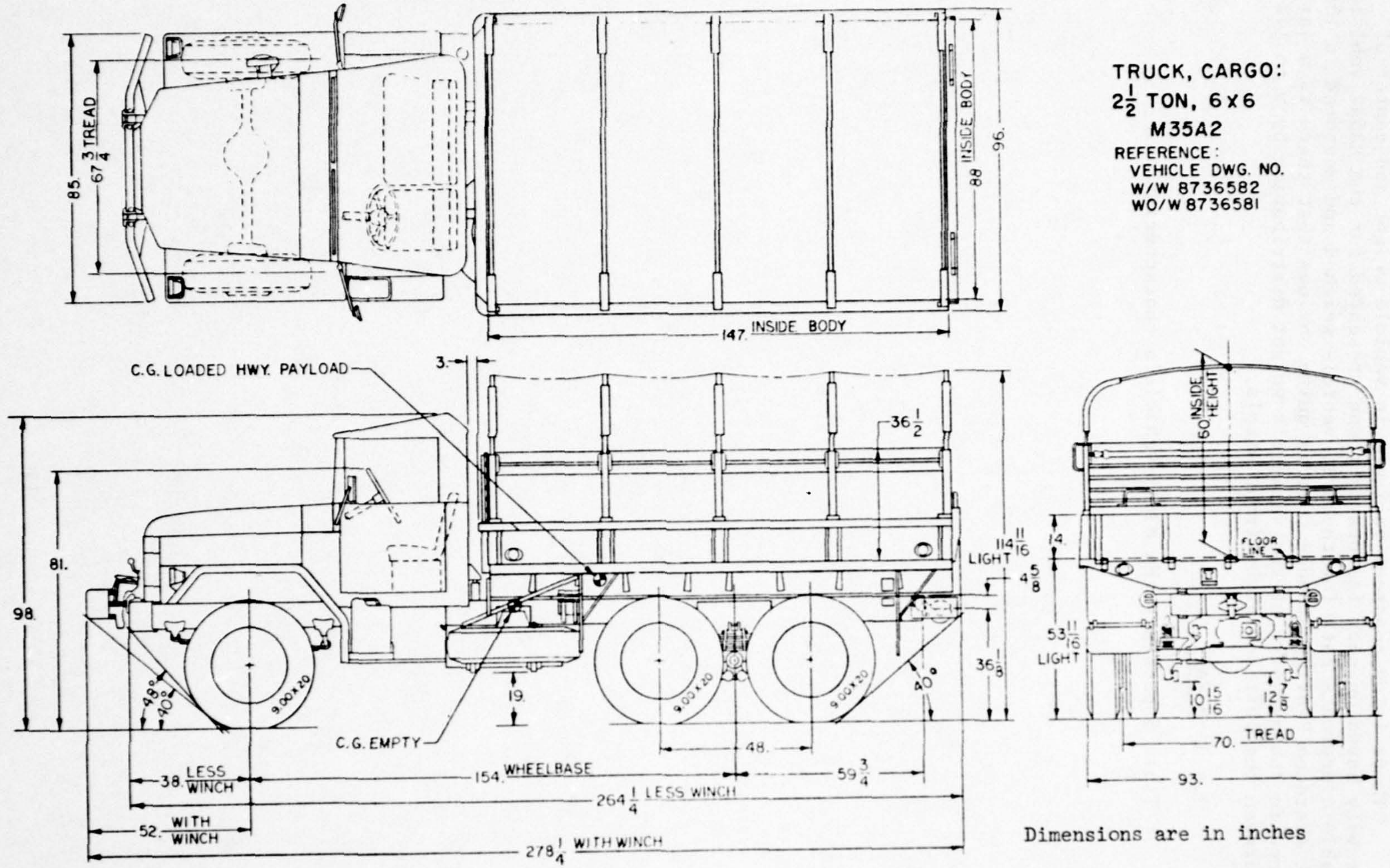
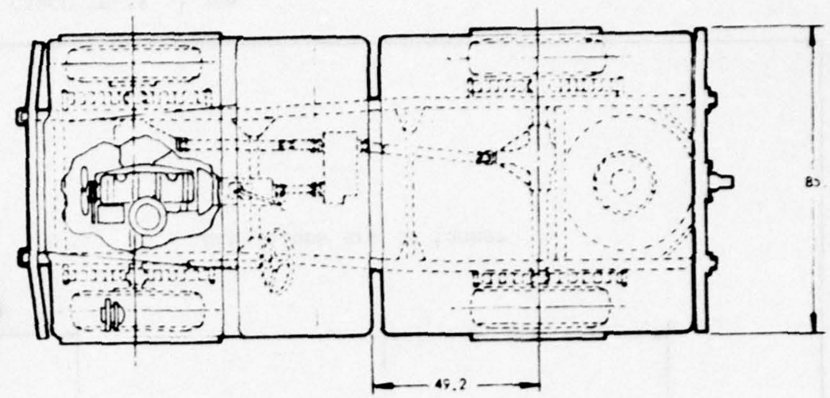
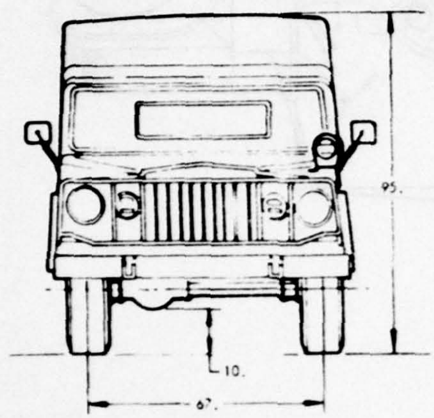
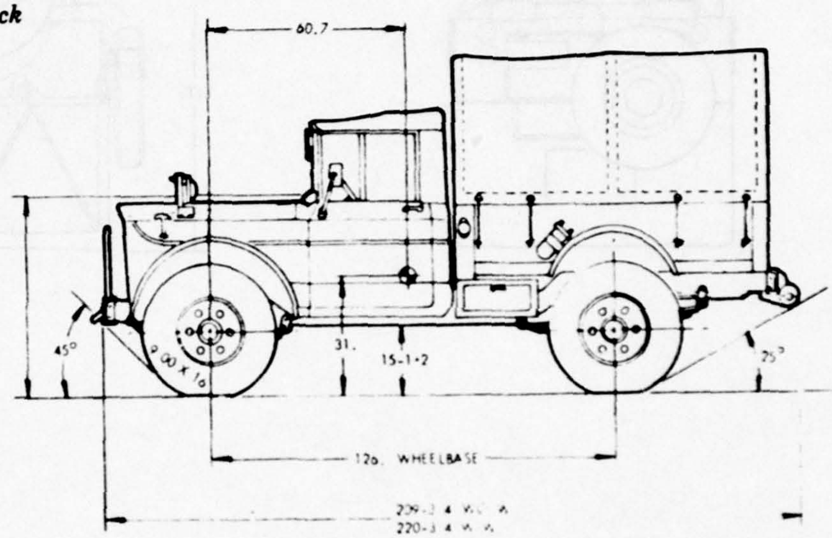


FIGURE 1: M35A2 CARGO TRUCK, 2½ TON (6x6)

S-250/G Electrical Shelter mounted on M715 Cargo Truck







Dimensions are in inches

FIGURE 2: M715 CARGO TRUCK, 1¼ TON

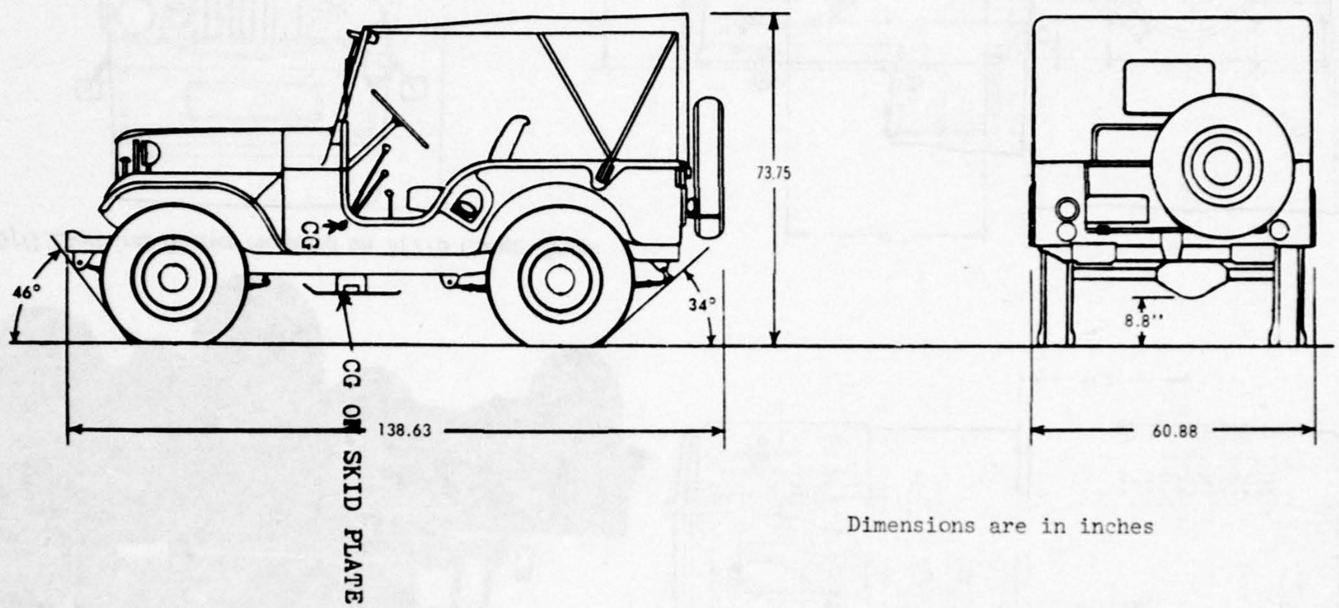
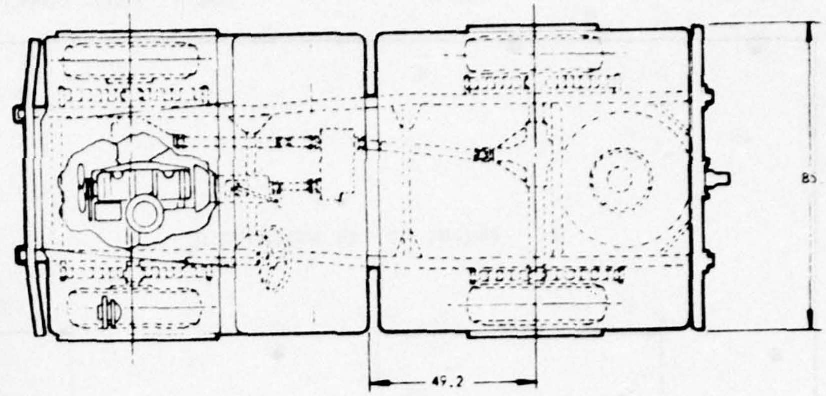
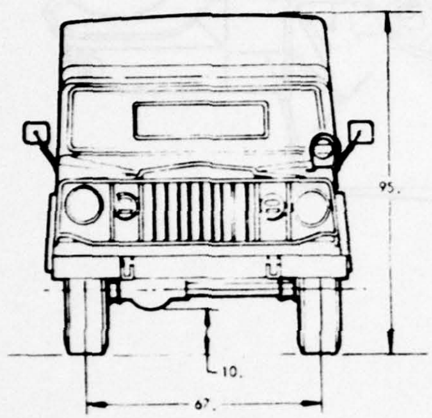
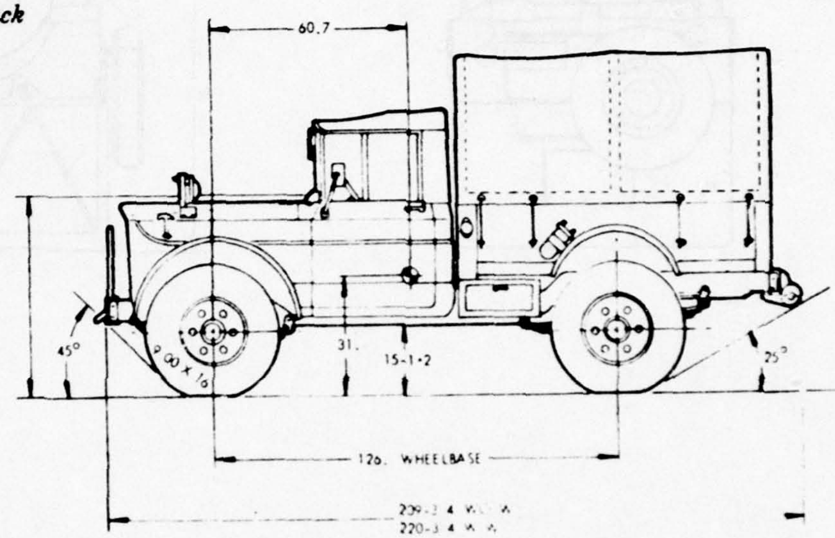


FIGURE 3: M38A1 CARGO TRUCK, ¼ TON

S-250/G Electrical Shelter mounted on M715 Cargo Truck







Dimensions are in inches

FIGURE 2: M715 CARGO TRUCK, 1¼ TON

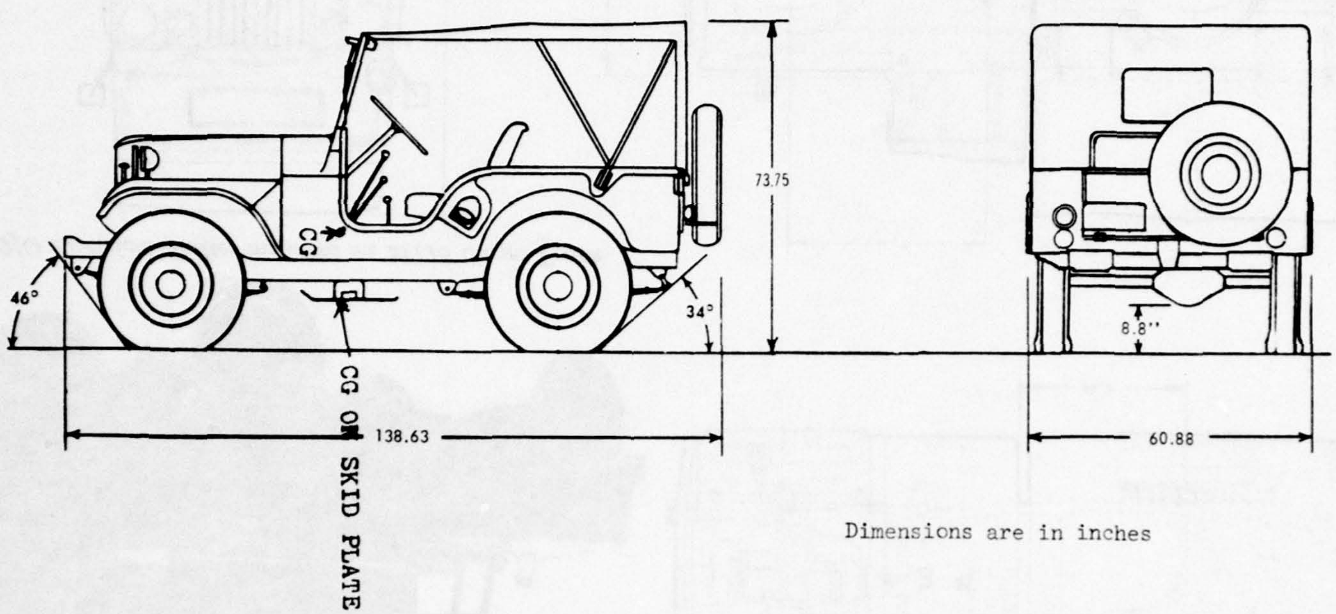


FIGURE 3: M38A1 CARGO TRUCK, ¼ TON

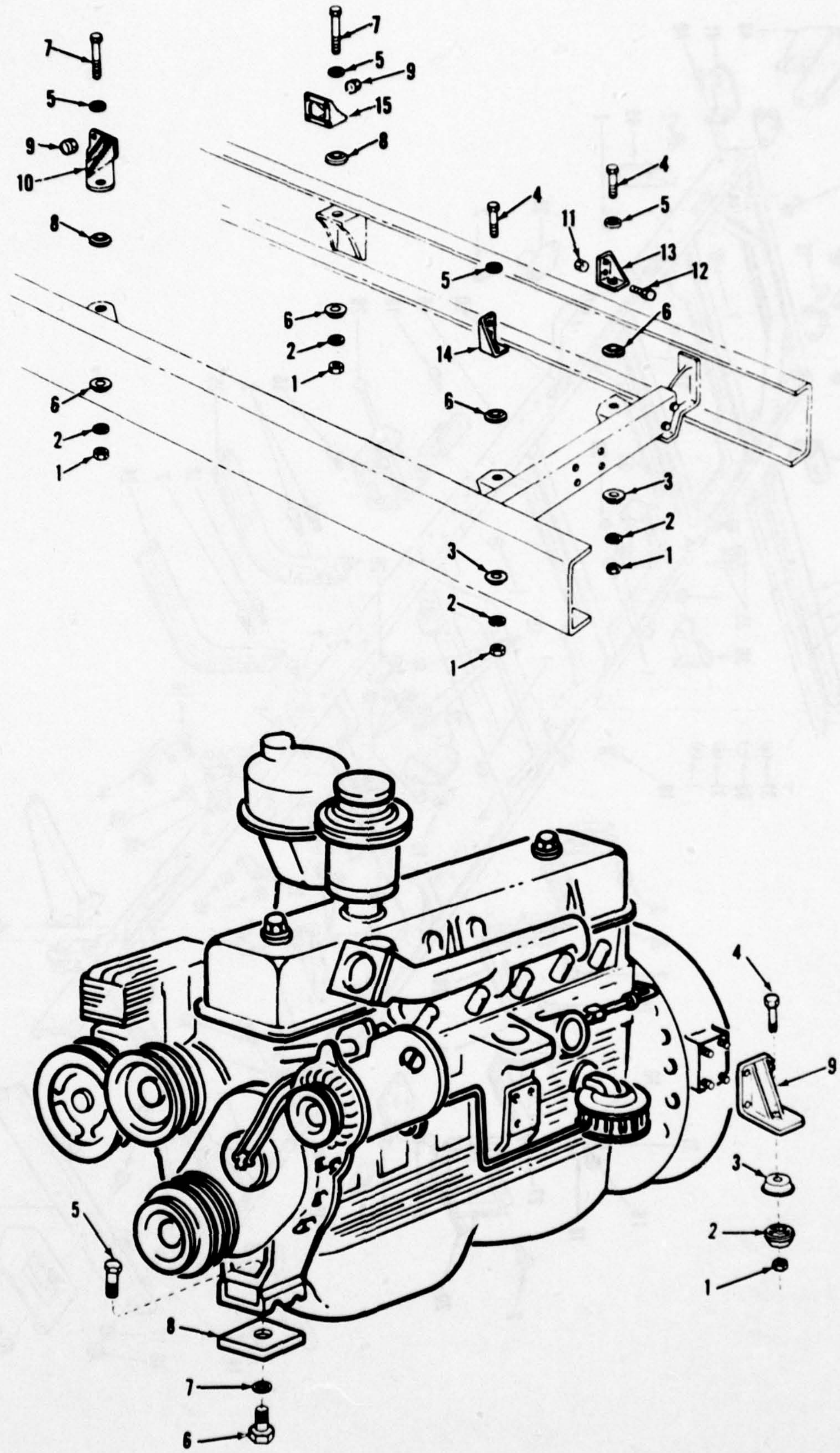


FIGURE 4: M35A2 ENGINE ATTACHMENT TO FRAME

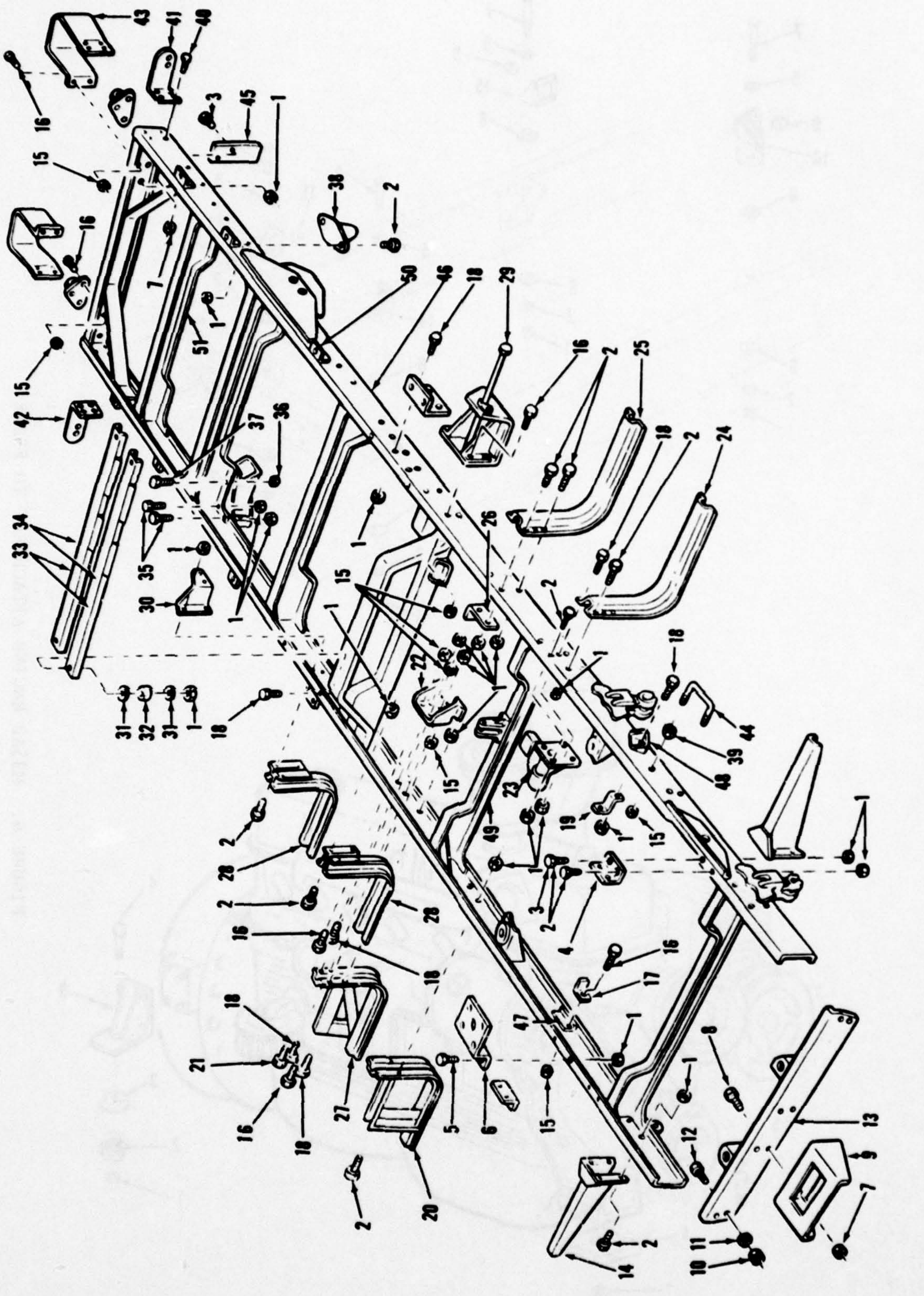


FIGURE 5: M35A2 FRAME

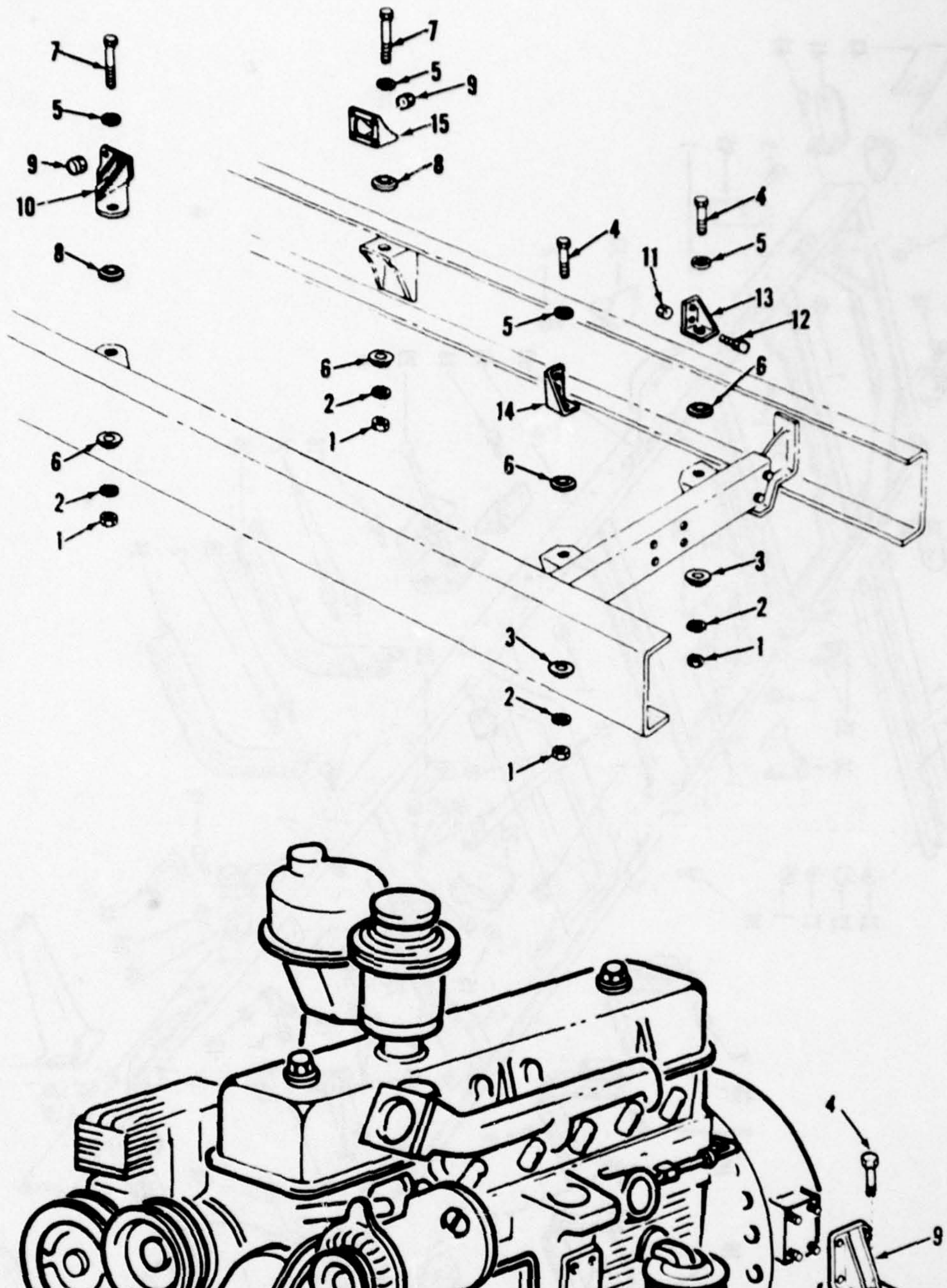


FIGURE 4: M35A2 ENGINE ATTACHMENT TO FRAME

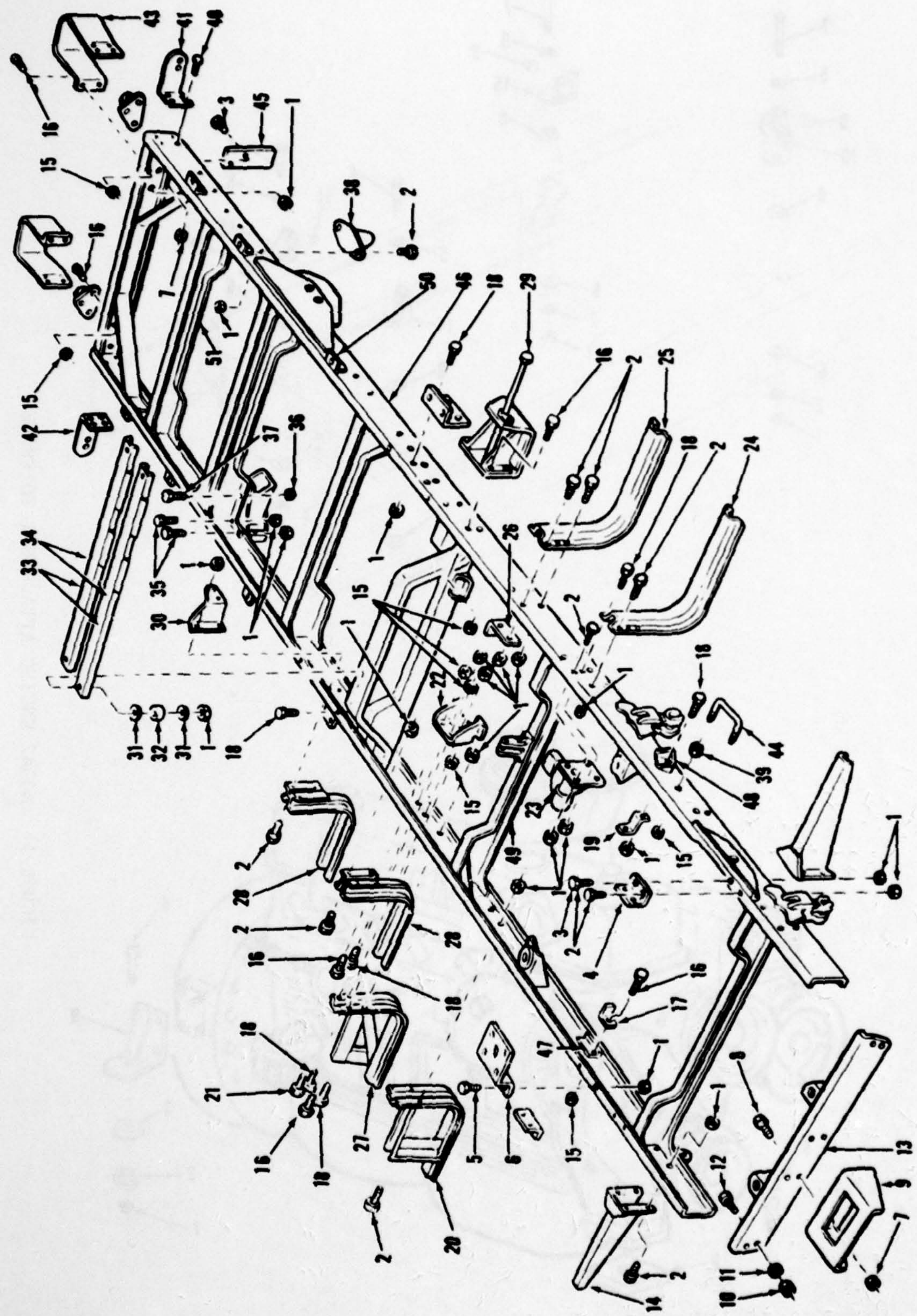


FIGURE 5: M35A2 FRAME

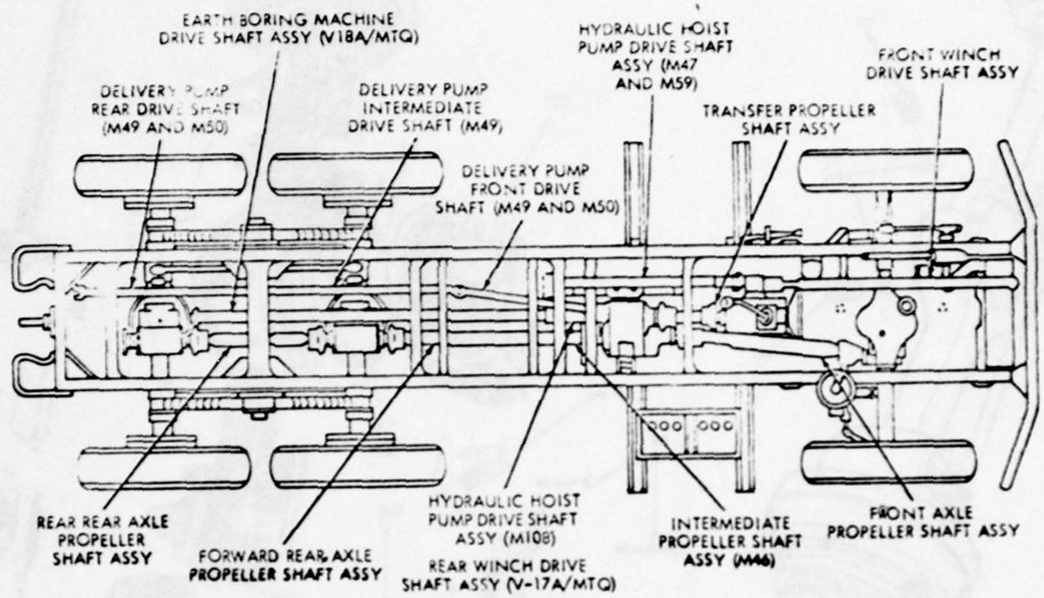


FIGURE 6: M35A2 FRAME OVERLAY OVER POWER TRAIN

(THE VARIOUS ASSEMBLIES ARE FOR ALL 2½ TON VEHICLES. DELETE THOSE THAT DO NOT APPLY TO THE M35A2.)

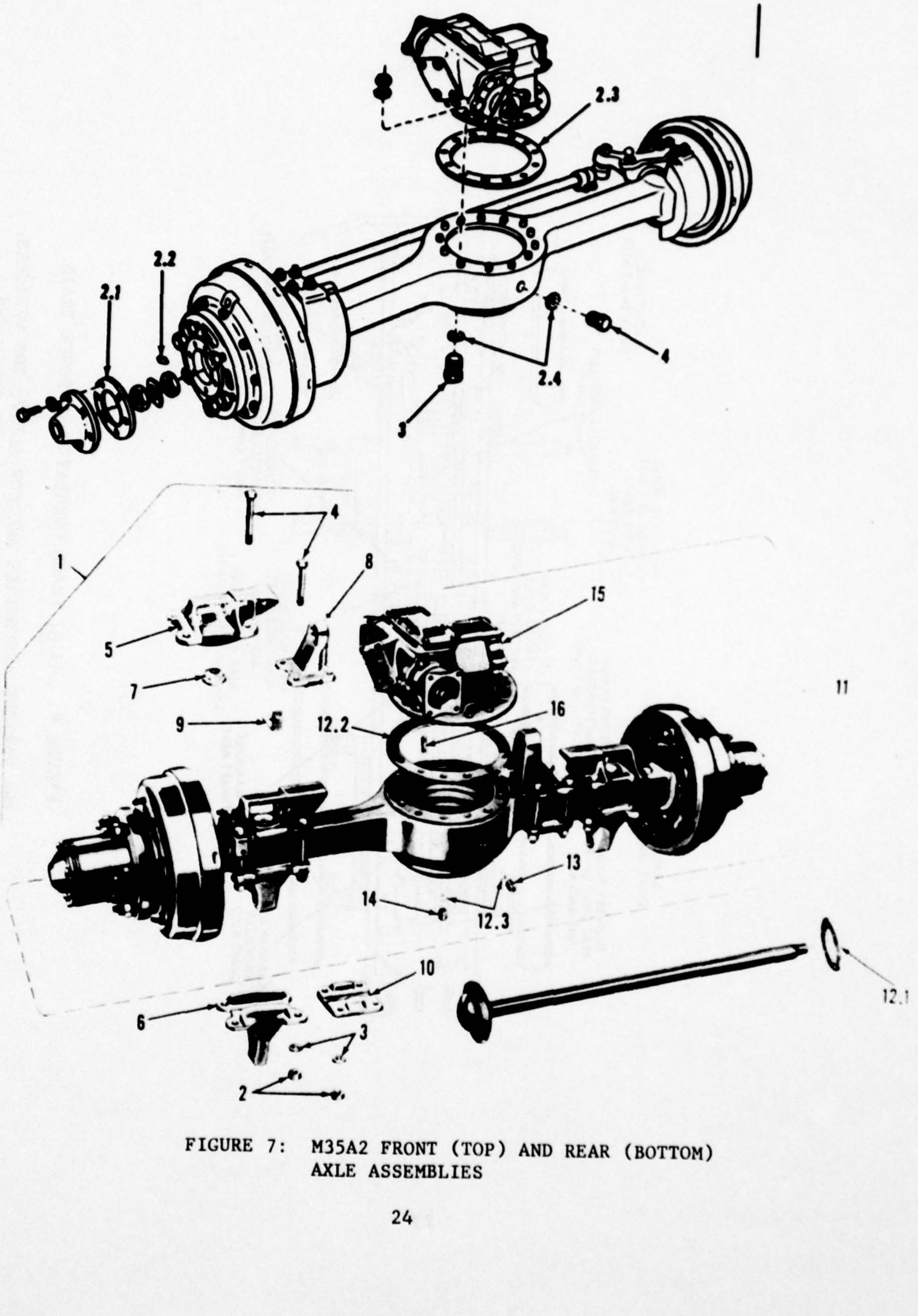


FIGURE 7: M35A2 FRONT (TOP) AND REAR (BOTTOM) AXLE ASSEMBLIES

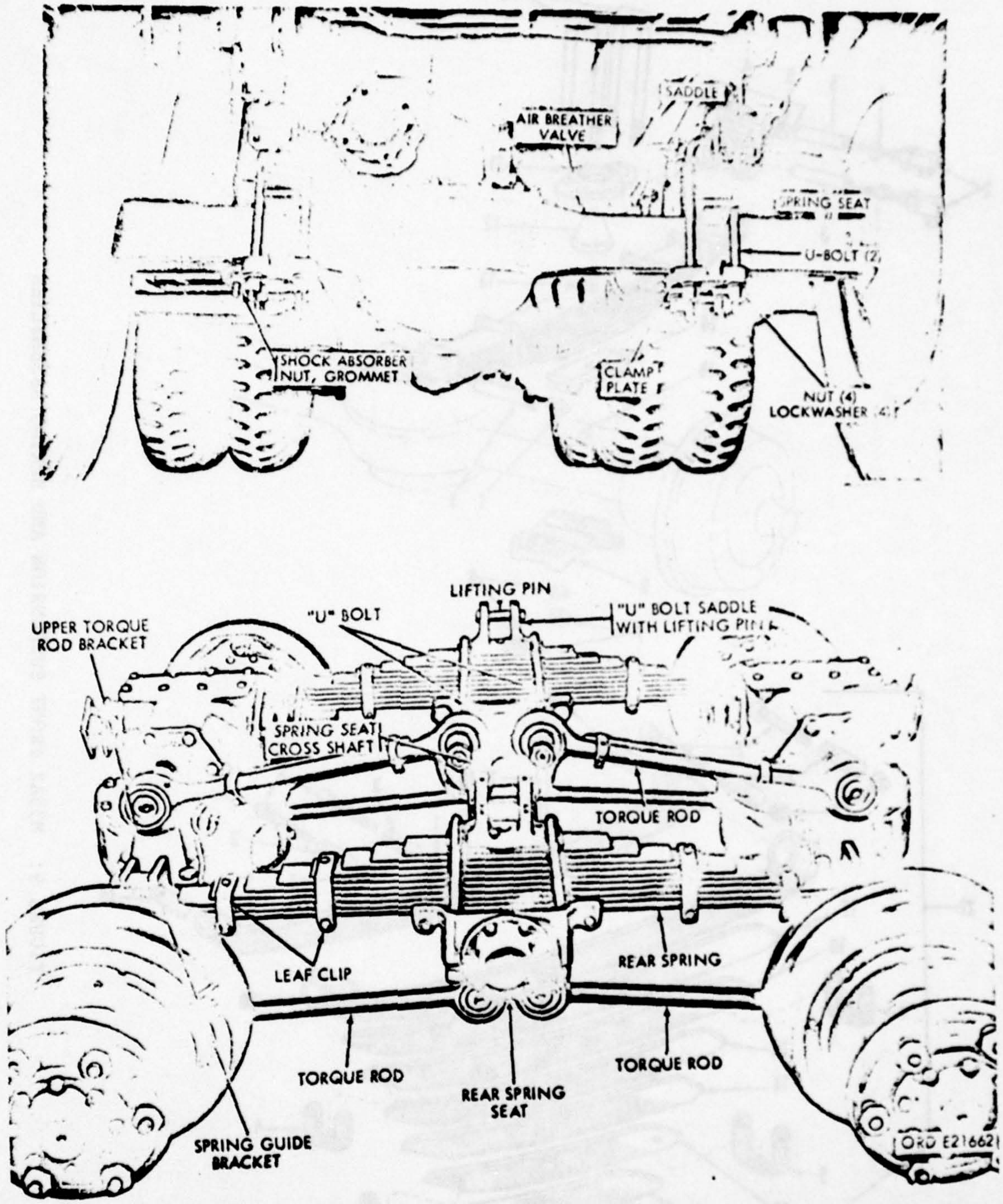


FIGURE 8: M35A2 FRONT AXLE INSTALLED (TOP) AND REAR SPRING AND TORQUE RODS (BOTTOM)

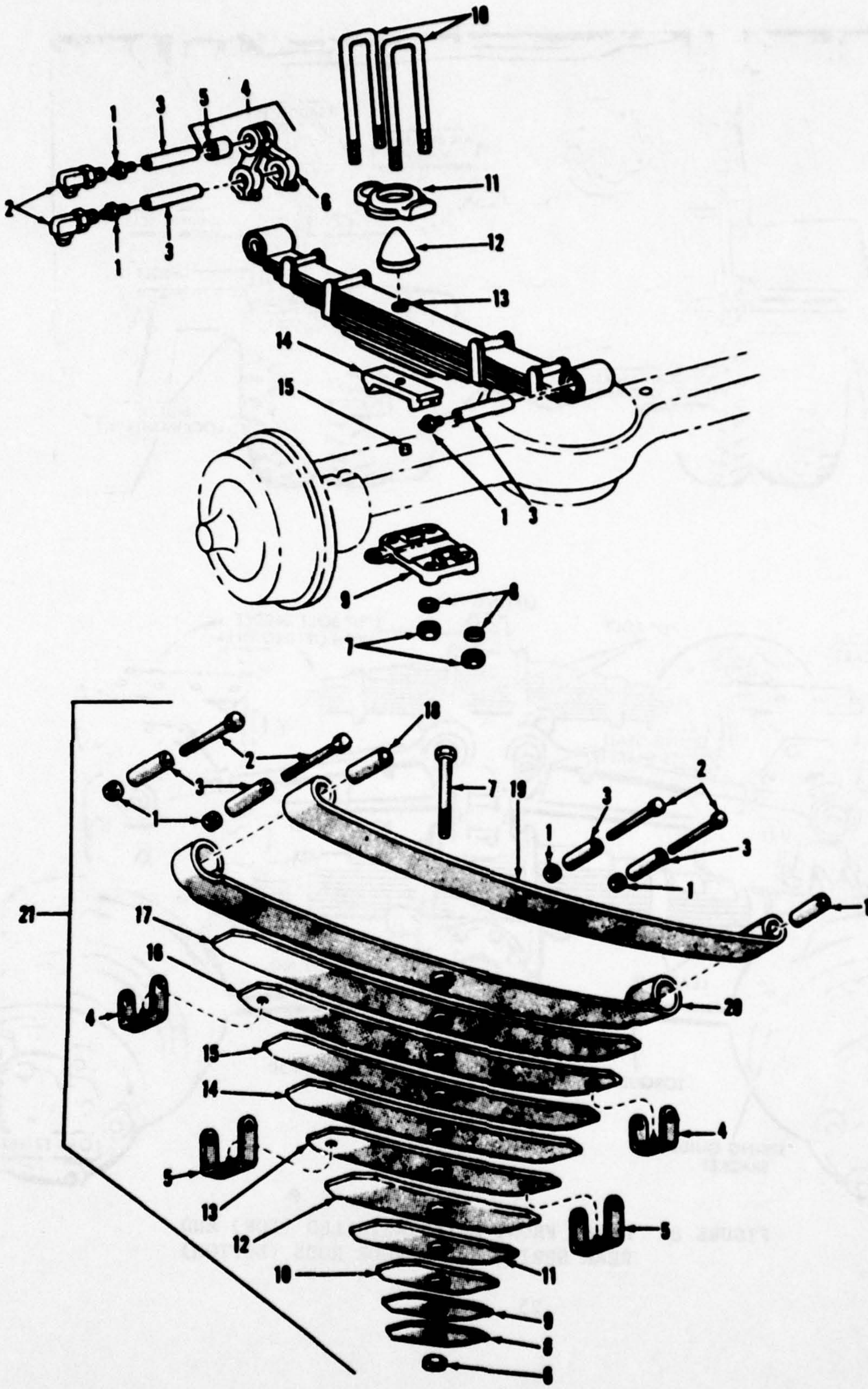


FIGURE 9: M35A2 FRONT SUSPENSION AND SPRING ASSEMBLIES

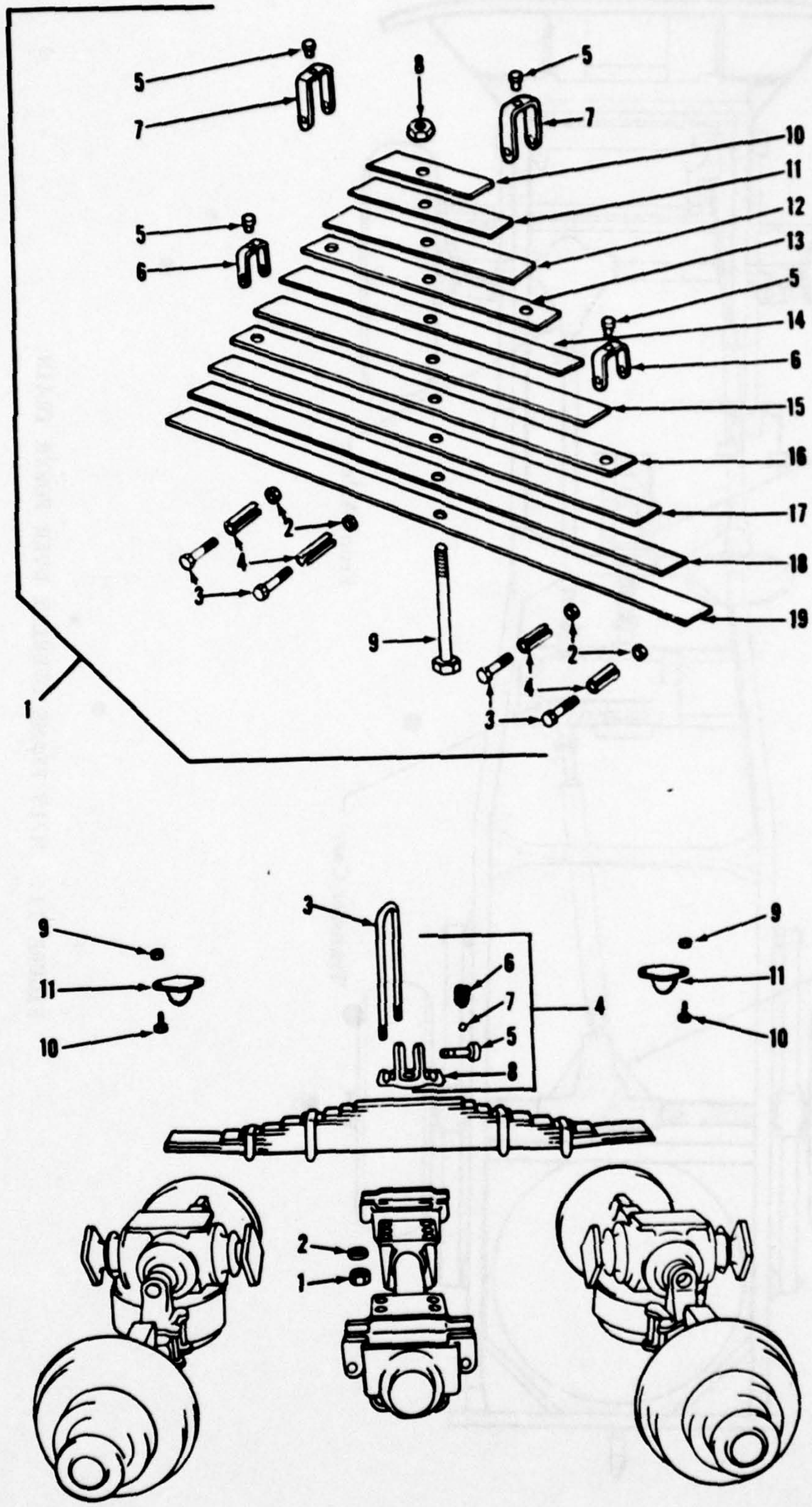


FIGURE 10: M35A2 REAR SUSPENSION AND SPRING ASSEMBLIES

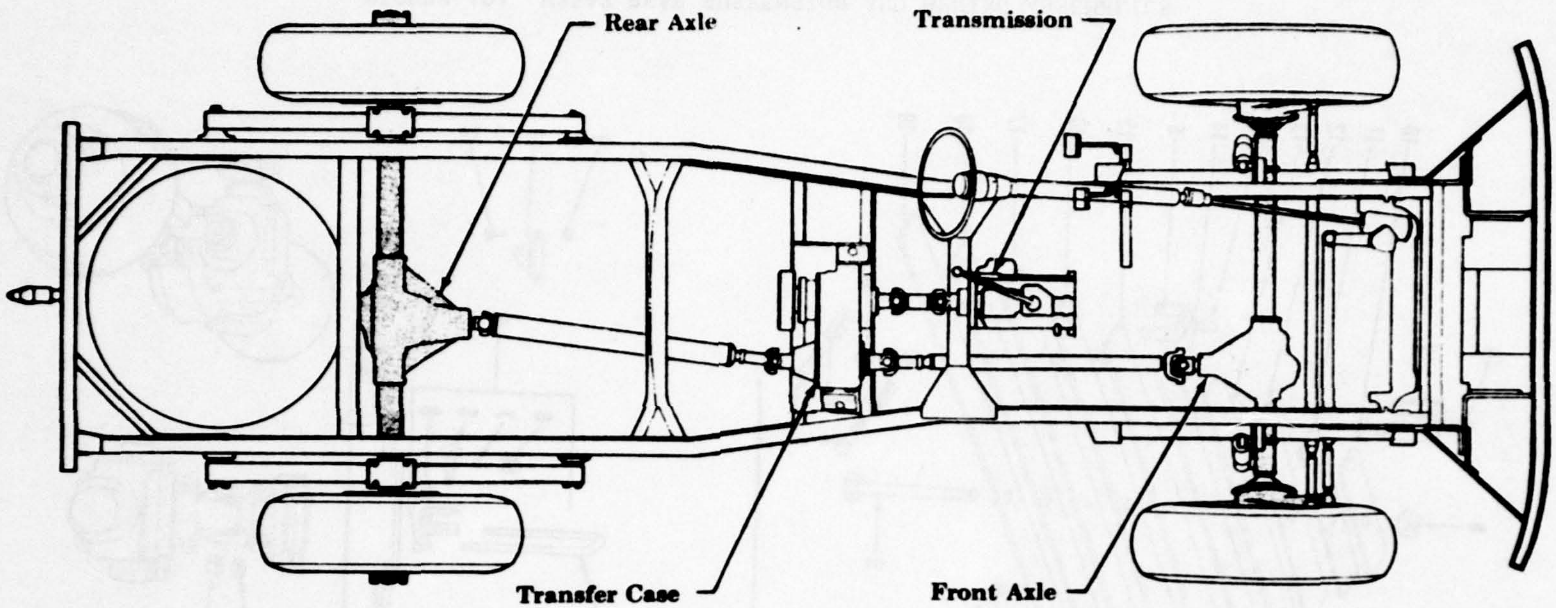


FIGURE 11: M715 FRAME OVERLAY OVER POWER TRAIN

TABLE 1. WEIGHT, DIMENSIONS, AND CENTER OF GRAVITY OF AN M35A2 VEHICLE

	WITHOUT WINCH	WITH WINCH
CURB WEIGHT, FULLY EQUIPPED, LESS PAYLOAD AND CREW		
Front Axle	5980 lbs.	6580 lbs.
Rear Bogie	7420 lbs.	7320 lbs.
Total	13400 lbs.	13900 lbs.
PAYLOAD		
Cross Country (Less Crew	5000 lbs.	5000 lbs.
Highway and Gear)	10000 lbs.	10000 lbs.
GROSS WEIGHT, FULLY EQUIPPED, PLUS PAYLOAD AND CREW		
Front Axle	6976 lbs.	7472 lbs.
Rear Bogie	16824 lbs.	16828 lbs.
Total	23800 lbs.	24300 lbs.
TOWED LOAD ALLOWANCE		
Cross Country	6000 lbs.	6000 lbs.
Highway	10000 lbs.	10000 lbs.
SHIPPING DIMENSIONS		
Cu. Ft.	1187	1252
Sq. Ft.	176	186
LENGTH	264¼ in.	278¼ in.
WIDTH	96 in.	96 in.
HEIGHT		
Overall Height	114 11/16 in.	114 11/16 in.
Lowest Operable	81 in.	81 in.
CENTER OF GRAVITY (AT CURB WEIGHT)		
Above Ground	38 in.	38 in.
Rear of Centerline of Front Axle	85.5 in.	81 in.
CENTER OF GRAVITY LOCATION (WITH HIGHWAY PAYLOAD)		
Above Ground	46.5 in.	46 in.
Rear of Center line of Front Axle	113 in.	110 in.

TABLE 2. M35A1 WEIGHT DISTRIBUTION

	Weight, lb.			
	Payload Condition			
Wheel Position	Curb[a]	Cross-country[b]	Secondary[b]	Highway[b]
Left Front	3450	3730	3770	3830
Right Front	3600	3760	3790	3880
Left Intermediate	1830	3060	3400	4170
Right Intermediate	1930	3210	3650	4320
Left Rear	1890	3200	3660	4480
Right Rear	1920	3170	3560	4430
Total	14620	20130	21830	25110

a With OEM, without driver.

b With OEM, with 185 pound driver and 170 pound co-driver.

TABLE 3. WEIGHTS, DIMENSIONS OF, AND CENTER OF GRAVITY OF THE M715 1¼ TON VEHICLE

	WITHOUT WINCH	WITH WINCH
CURB WEIGHT, FULLY EQUIPPED LESS PAYLOAD AND CREW		
Front Axle	2800 lbs.	3300 lbs.
Rear Axle	2700 lbs.	2700 lbs.
Total	5500 lbs.	6000 lbs.
PAYLOAD (Less Crew and Gear--400 lbs.)		
Cross Country (limited use)	2500 lbs.	2500 lbs.
Highway	3000 lbs.	3000 lbs.
GROSS WEIGHT, FULLY EQUIPPED, PLUS PAYLOAD AND CREW		
Front Axle	3000 lbs.	3500 lbs.
Rear Axle	5400 lbs.	5400 lbs.
Total	8400 lbs.	8900 lbs.
TOWED LOAD ALLOWANCE		
Cross Country (limited use)	2840 lbs.	2840 lbs.
Highway	3590 lbs.	3590 lbs.
SHIPPING DIMENSIONS		
Cu. Ft.	606	640
Sq. Ft.	124	130
LENGTH	209 3/4 in.	220 3/4 in.
WIDTH	85 in.	85 in.
HEIGHT		
Overall Height	95 in.	95 in.
Lowest Operable	59 in.	59 in.
CENTER OF GRAVITY (At Curb Weight)		
Above Ground	31 in.	31 in.
Rear of Centerline of Front Axle	60.7 in.	56.6 in.
CENTER OF GRAVITY LOCATION (With Highway Payload)		
Above Ground	32 in.	32 in.
Rear of Centerline of Front Axle	84.4 in.	80.4 in.

TABLE 4. M715 (1¼ Ton) WEIGHT DISTRIBUTION

1967 WEIGHT MEASUREMENTS AT ABERDEEN (Note: fuel tank is on left)

Left Front Wheel -- 1620 lbs.		
Right Front Wheel - 1570 lbs.	Note: difference of 50 lbs.	
Left Rear Wheel -- 1420 lbs.		
Right Rear Wheel - 1290 lbs.	Note: difference of 130 lbs.	
TOTAL -- 5900 lbs.		

C.G. -- curb weight (including fuel, etc. -- less operator)

1" left of center line (plane) of vehicle
70" forward of rear axle center line
26 7/8" above ground

Tires -- Goodyear 9:00-16

25 psi pressure for front tires
45 psi pressure for rear tires

TABLE 5. WEIGHTS, DIMENSIONS OF, AND CENTER OF GRAVITY OF THE M38A1 VEHICLE

CURB WEIGHT, LESS PAYLOAD AND CREW	
Front Axle	1430 lbs.
Rear Axle	1310 lbs.
Total	2740 lbs.
PAYLOAD	
Highway	1200 lbs.
Cross Country	800 lbs.
TOWED LOAD ALLOWANCE	
Highway	2000 lbs.
Cross Country	1500 lbs.
SHIPPING DIMENSIONS	
Cu. Ft. W/Top Down	258
Sq. Ft. W/Top Down	58.613
LENGTH	138.63 in.
WIDTH	60.88 in.
HEIGHT	73.75 in.
CENTER OF GRAVITY	
Above Ground	26.25 in.
Rear of Centerline of Front Axle	38.525 in.

3.0 DYNAMIC MODELING OF VEHICLE

The Kaman-Avidyne dynamic model should be modified for the vehicle description considered in the previous section. For general application to either a dual or single rear axle vehicle, the models are schematically illustrated in : Figure 12, General Geometrical Configuration; Figure 13, Dynamic Model of Truck Shelter and Racks System; Figure 14, Generalized Coordinates g_i (inertia system), $\bar{g}_i$ (reference body system); Figure 15, Equilibrium Position; Figure 16, Displacement of the Total System; and Figure 17, Model of Two Symmetric Racks.

In order to improve the vehicles' dynamic model systems as indicated in Table 6, Figures 12 through 17 are modifications of the original Kaman-Avidyne Figures 1 through 6.

Another modification that could possibly be made is that the frame could also act as a torque rod in a manner analogous to the bogie's tie and torque rods.

3.1 Modeling of Mechanical Properties for Springs, Shock Absorbers, and Tires

In predicting the response of a vehicle to either a blast loading, or ground shock, or nominal operating condition, or combinations of these and others requires a knowledge of the properties of the springs, shock absorbers, and tires as well as other components on the vehicle. The expressions that appear to be important are the force-deflection and force-velocity relations of the vehicles' components relative to the spring-shock absorbing system. These relations should consider most of the following parameters for the vehicle's spring, shock absorbers, and tires: components' cross-sectional properties, wear and age, surface, climate, temperature, and speed of vehicle. The properties of the tires include vertical stiffness, circumferential stiffness, cornering stiffness, camber stiffness, inflation pressure, bias ply, radial ply, ply rating, and tread patterns.

A general relation containing all of the above mentioned variables and parameters probably would be highly non-linear and hence has to be reduced to manageable relations that cover only certain applicable ranges of the parametric values. Based upon the limited data available in the literature and exploratory tests conducted by the author, some of the above data could be approximated by piece-wise linear (or polynomial) relations. The approximations should consider both loading and unloading of the springs and shock absorbers. For instance, the load-deflection relation for leaf springs has a hysteresis that could be significant. (The hysteresis is omitted in the Kaman-Avidyne model.) On the other hand, the tires' load deflection curves generally have a much smaller hysteresis than the springs' load-deflection curves and in some cases could be omitted.

The details of the information that have been obtained for springs, tires, and shock absorbers are voluminous and beyond the scope of current efforts. In the following paragraphs only the data relative to the vehicles M35A2, M715, and M38A1 are included to fit the Kaman-Avidyne computer model. The relations described in the next section as the data input to the computer program. Mechanical data for dynamic loading generally is not available and the significance of this data is illustrated, in the next section, for tires. The effect of inflation pressure on the mechanical properties has to be considered. High temperatures can be generated in the tires while the vehicle is either moving for sufficiently long periods of time (½ hour for high speeds) or exposed for long periods of time to the sun such as in the desert areas. Also, certain materials in the tires change their chemical structure when exposed to certain optical spectrums of the sunlight as well as to temperatures of the order of 200°F. The mechanical properties of the tire walls start to reduce significantly for temperatures above 150°F.

3.2 Load-Deflection Relations for Tires

The type of tire and load, (e.g. inflation pressure, bias ply versus transteel radials, tread patterns (open vs. rib), wear, and footprint) considerable affect the mechanical properties of the tires. Further, the difference between the mechanical properties for the dynamic vs. the static loading could be significant as it appears that the mechanical properties are very sensitive to stress- and strain- rates.

No data were obtainable for load-deflection curves for any of the tires of concern. Some data were available for the 9:00-20 steel radial tires but not for the bias ply tires. Except for the limited testing performed by this writer, no data were available for either the 9:00-16 or the 7:00-16 tires. Generally, the vertical load-deflection curve is rather linear and is illustrated in Figure 24 for a 9:00-20 tire inflated to approximately 50 psi and subjected to static and dynamic loads. The curves are to be considered only for illustrative purposes.

TABLE 6. LIST OF RECOMMENDED MODIFICATIONS TO KAMAN-AVIDYNE DYNAMIC MODEL

KAMAN-AVIDYNE FIGURE NUMBER	MODIFICATIONS RECOMMENDED
1	* Change the two front independently suspended wheels to a coupled suspension system. Change the mass distribution so that the body and shelter are two distinct masses. Remove tie wires to ground. (See Figure 12)
2	* Move front and aft suspension springs and dampers which are located directly over the wheels in the original model to a new position which is inwardly located over the axle away from the wheels. Also include a mass-spring damper relation between body and shelter. (See Figure 13)
3	* Modify generalized coordinates and masses consistent with the new front axle model; Note that $M^{(5)}$ could be equal to zero in the modified model, i.e. if it is symmetric about the center plane*. (See Figure 14)
4	* New coordinates f and g define the x-dimensions of the modified suspension system locations. The front axle C.G. is assumed to be located at (0,-e,a)*. (See Figure 15)
5	* The displacements δ_3, δ_6, δ_9, δ_{12}, δ_{15}, and δ_{18} occur at the modified suspension spring damper location. If required δ_b is the displacement of the body. (See Figure 16)
6	* No change. (See Figure 17)

* The front axle C.G. is actually located to one side of the central vertical (Fore and aft) plane of the vehicle. Likewise, the C.G. of the vehicle with or without shelter is located off the vertical (fore and aft) plane as discussed in the paragraphs on the mass distribution.

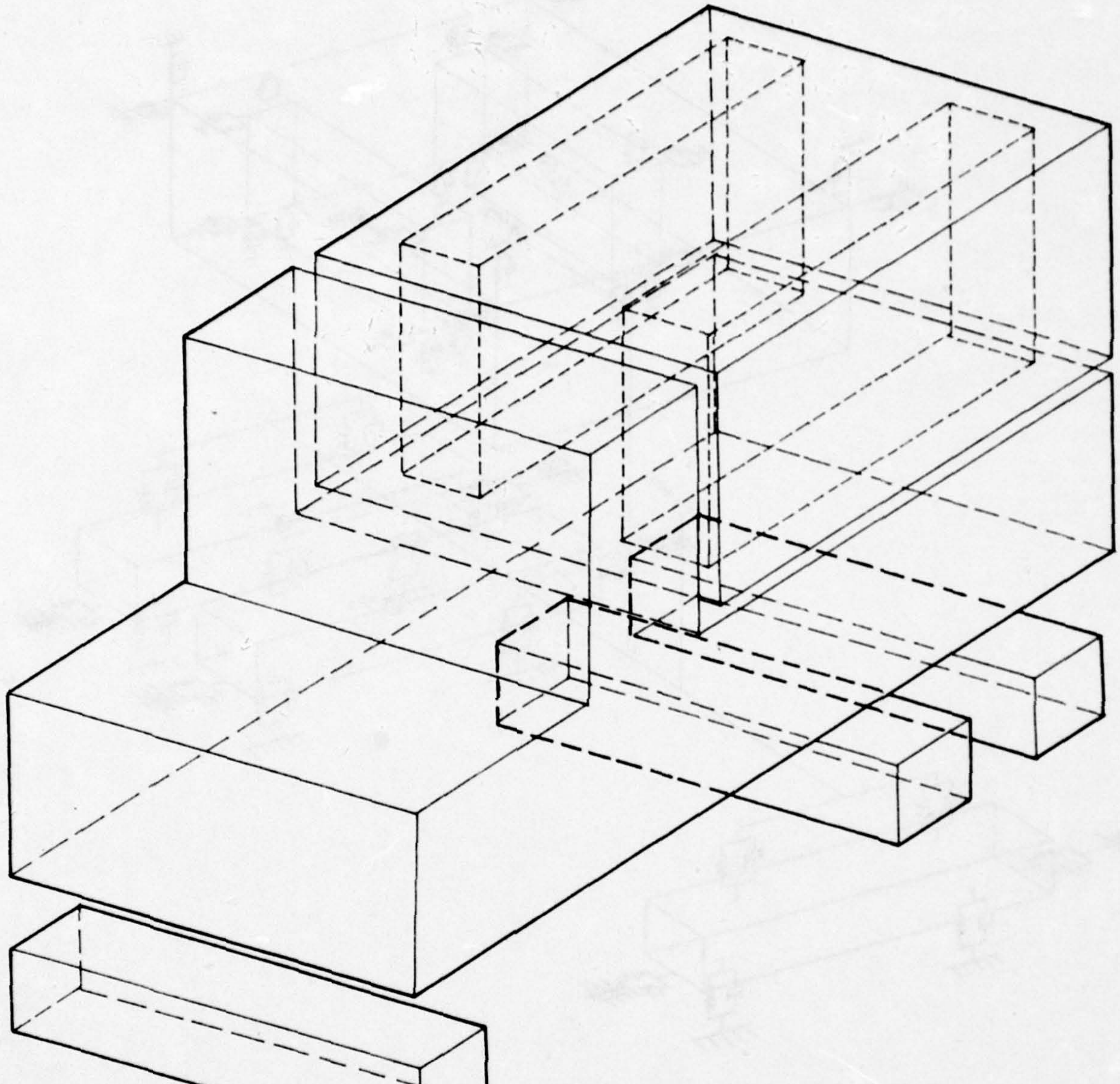


FIGURE 12. MODIFIED GENERAL CONFIGURATION.

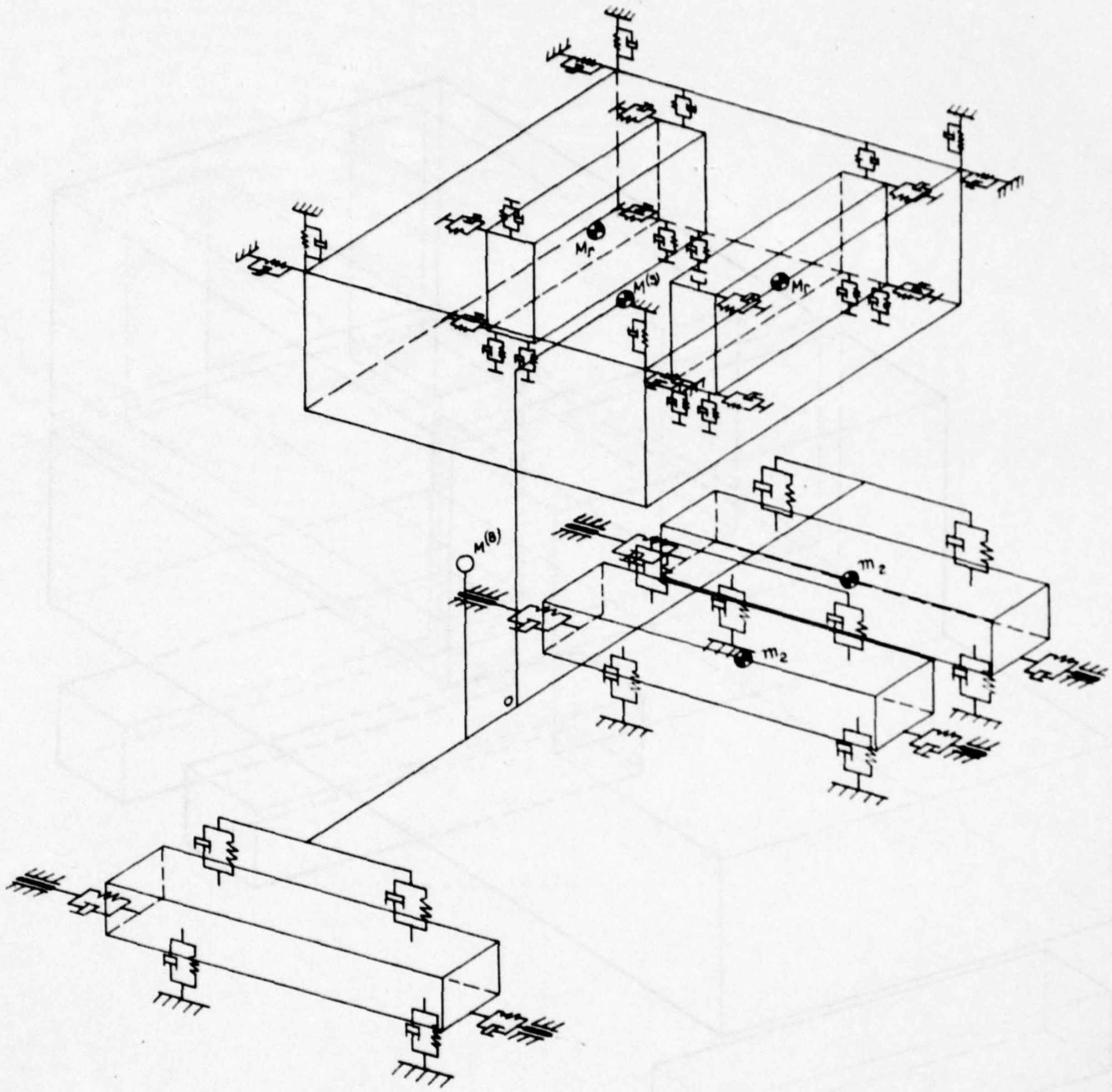


FIGURE 13. MODIFIED DYNAMIC MODEL OF TRUCK SHELTER AND RACKS SYSTEM.

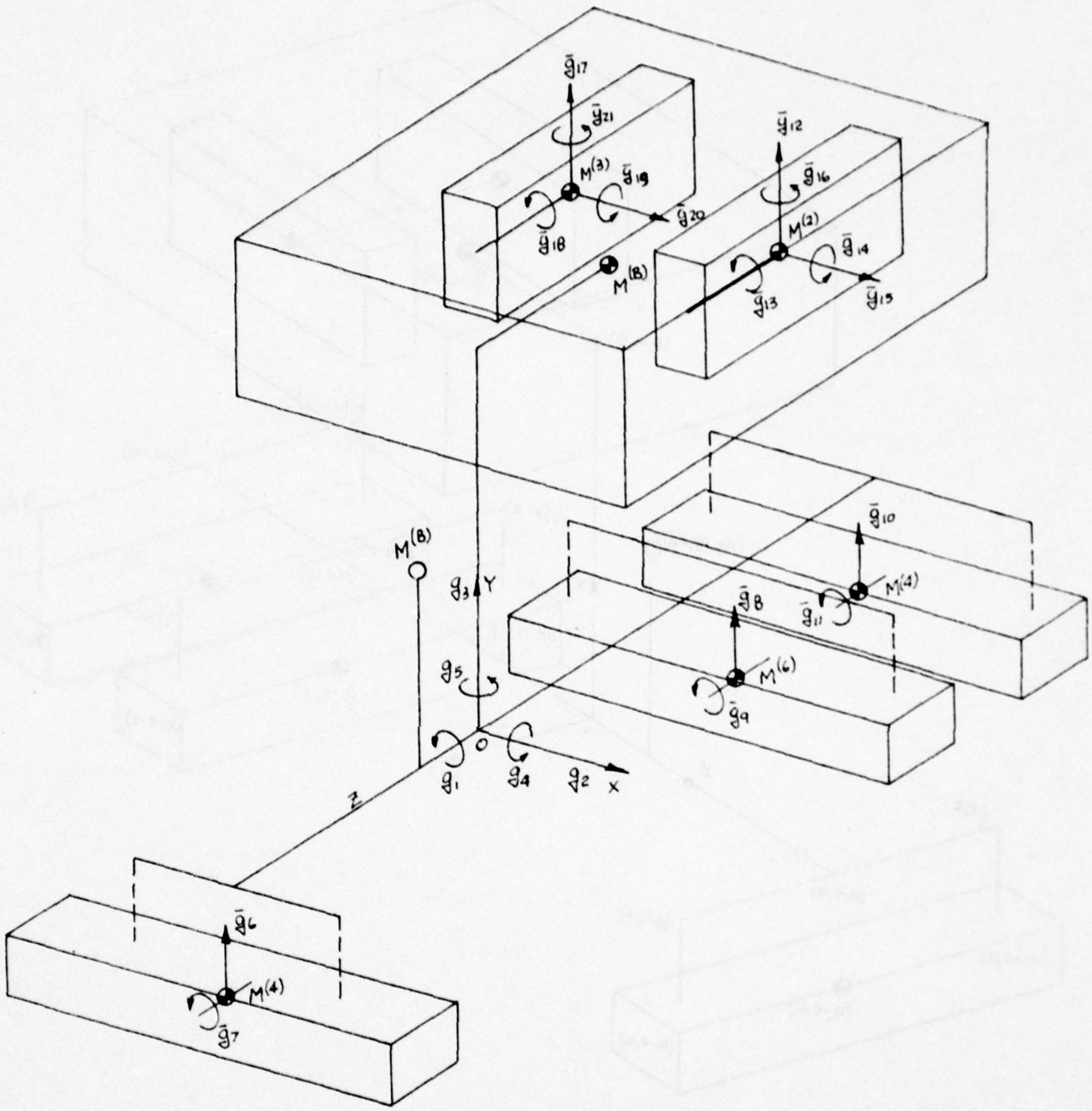


FIGURE 14. MODIFIES GENERALEZED COORDINATES g_i
(INERTIAL SYSTEM) $\bar{g}_i$ (REFERENCE BODY SYSTEM.

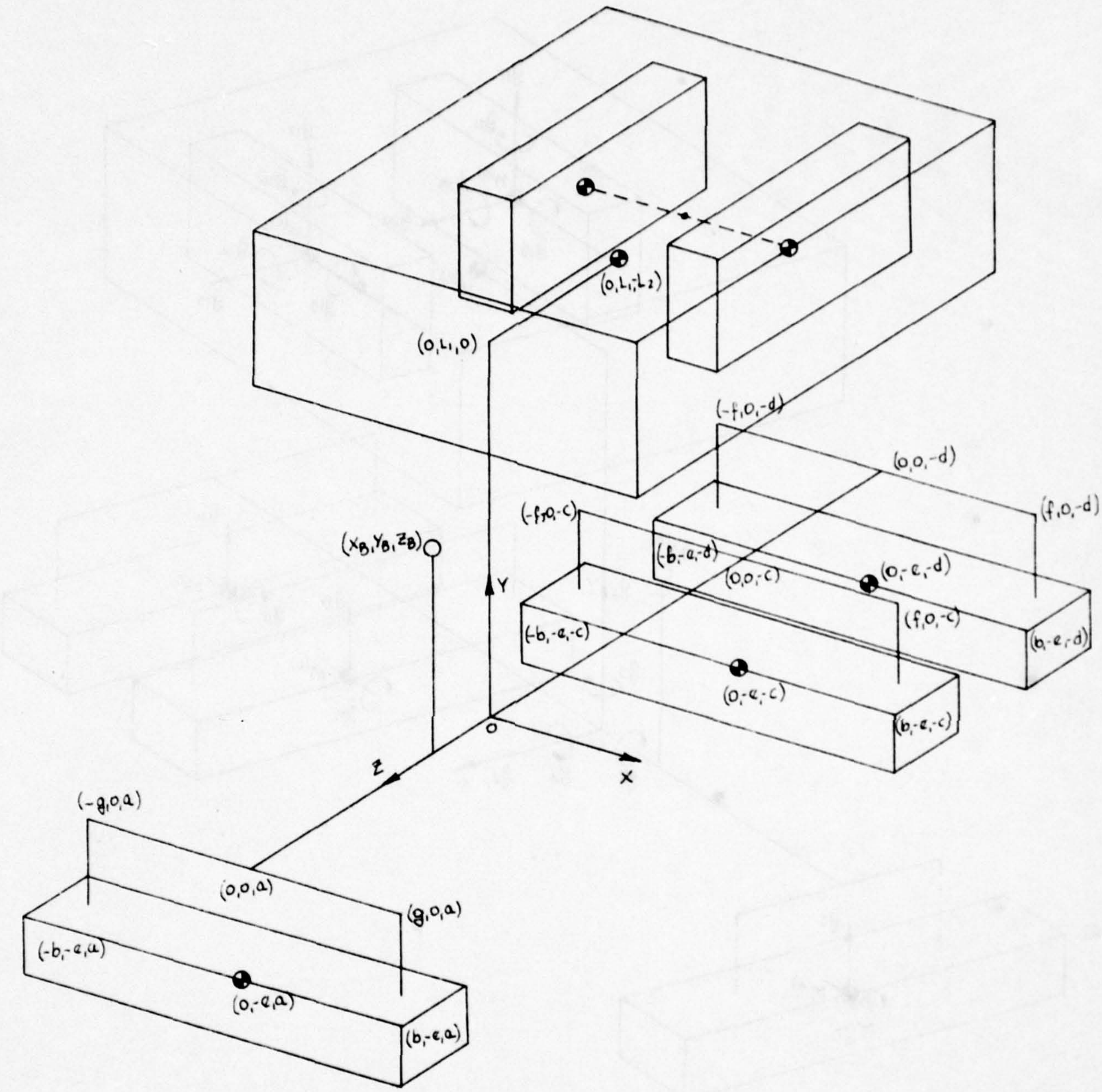


FIGURE 15. MODIFIED EQUILIBRIUM POSITION.

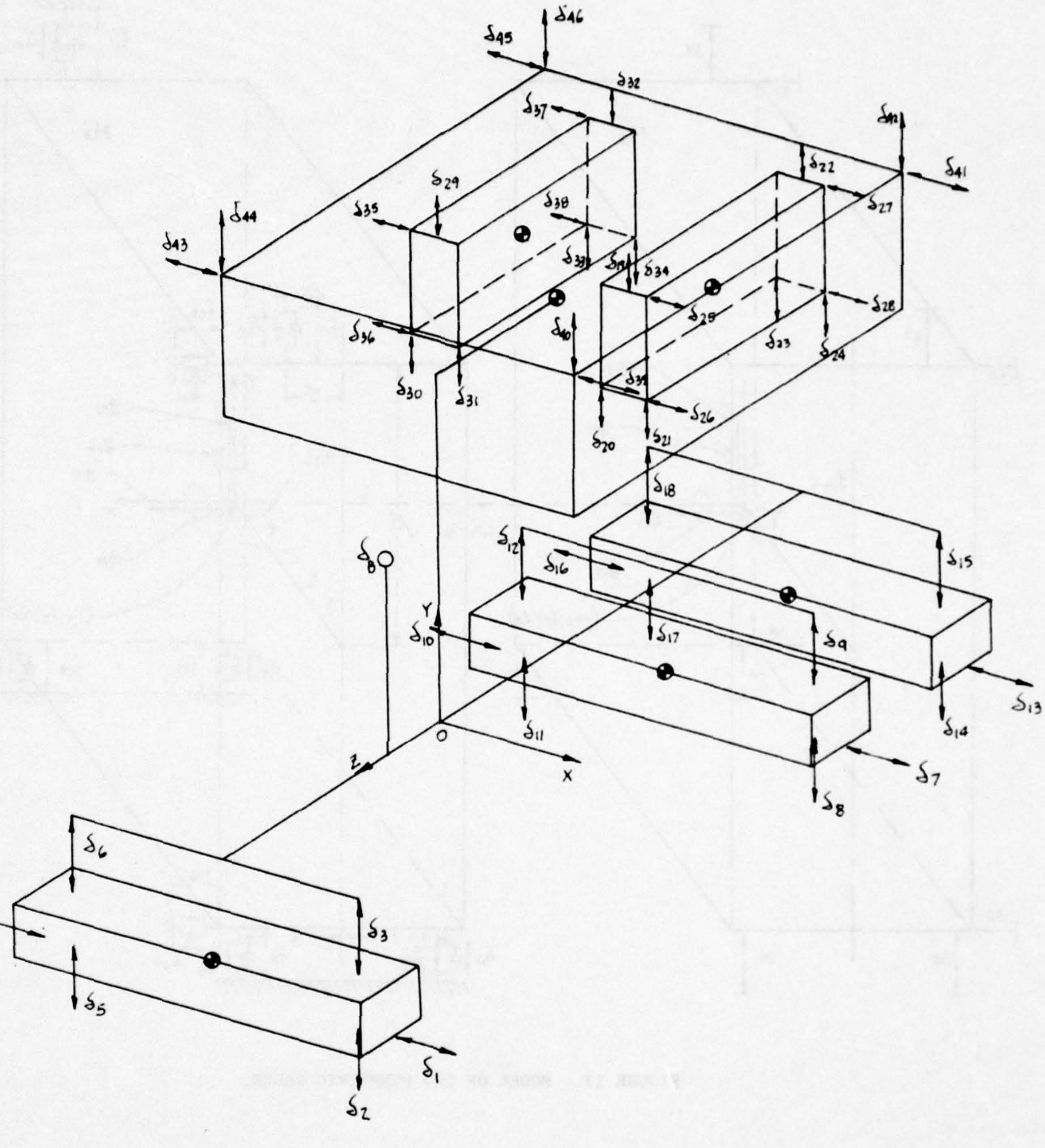


FIGURE 16. MODIFIED DISPLACMENT OF THE TOTAL SYSTEM.

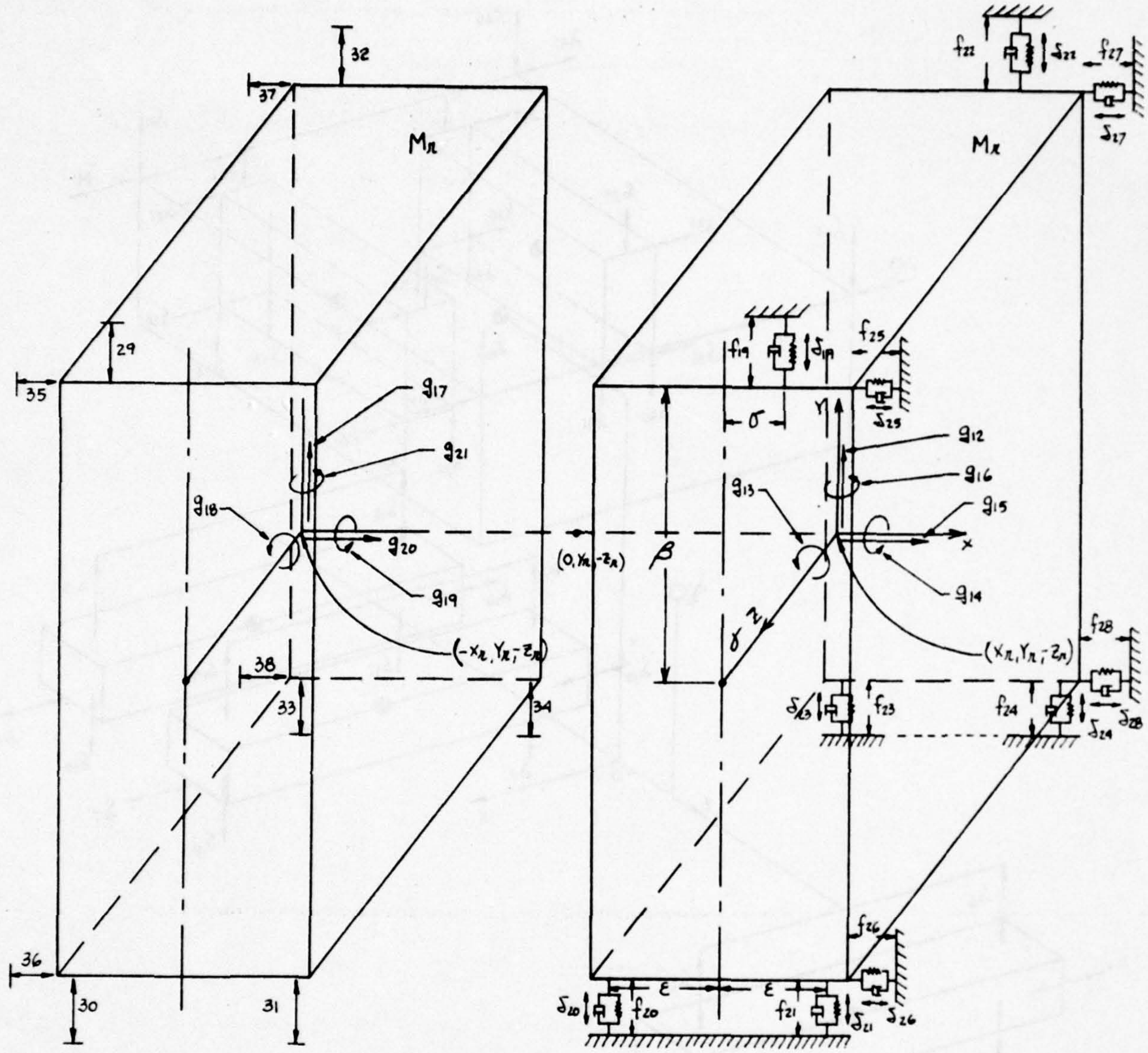


FIGURE 17. MODEL OF TWO SYMMETRIC RACKS.

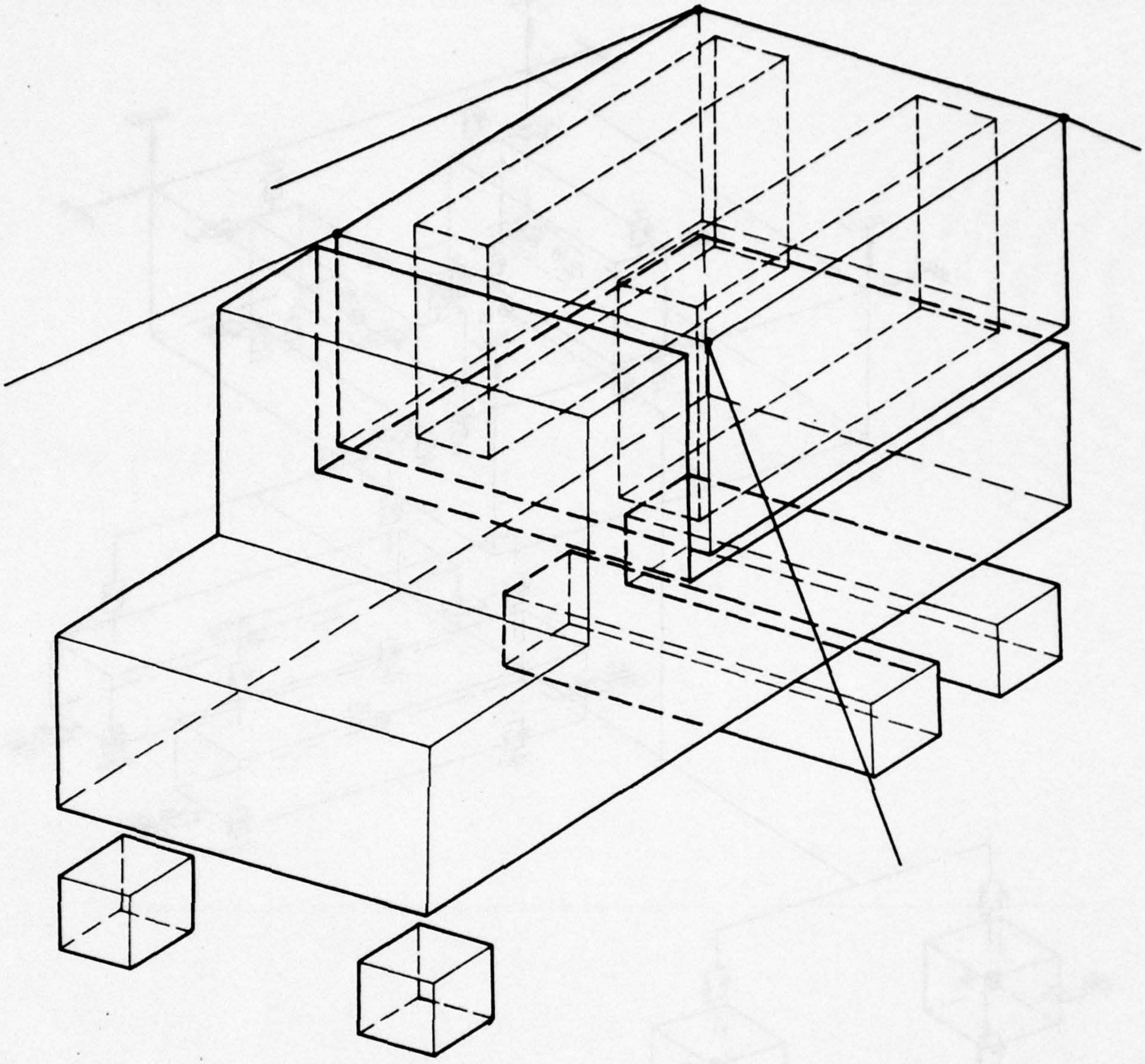


FIGURE 18. GENERAL CONFIGURATION.
(KAMAN-AVIDYNE FIGURE 1)

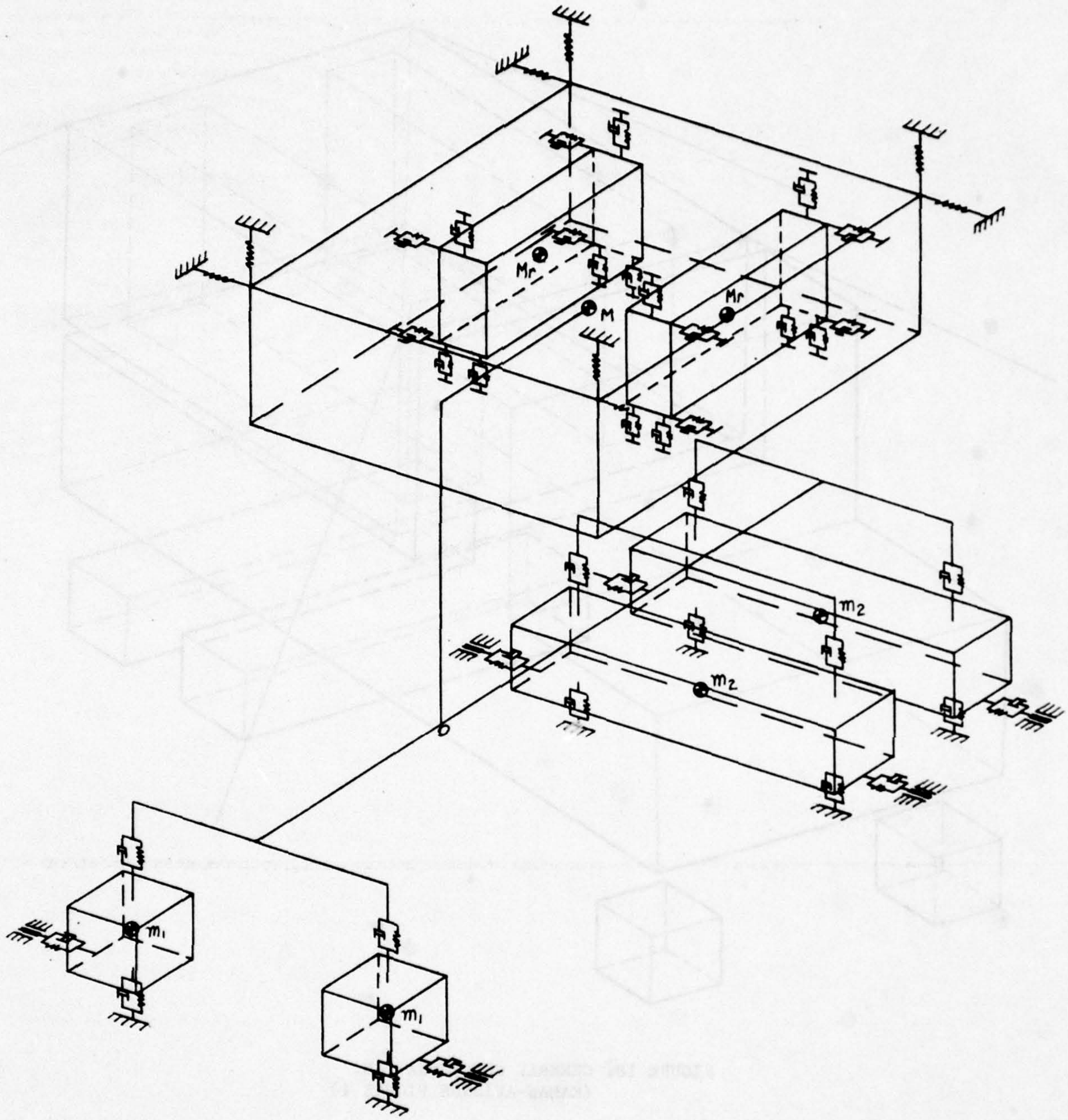


FIGURE 19. DYNAMIC MODEL OF TRUCK SHELTER AND RACKS SYSTEM.
(KAMAN-AVIDYNE FIGURE 2)

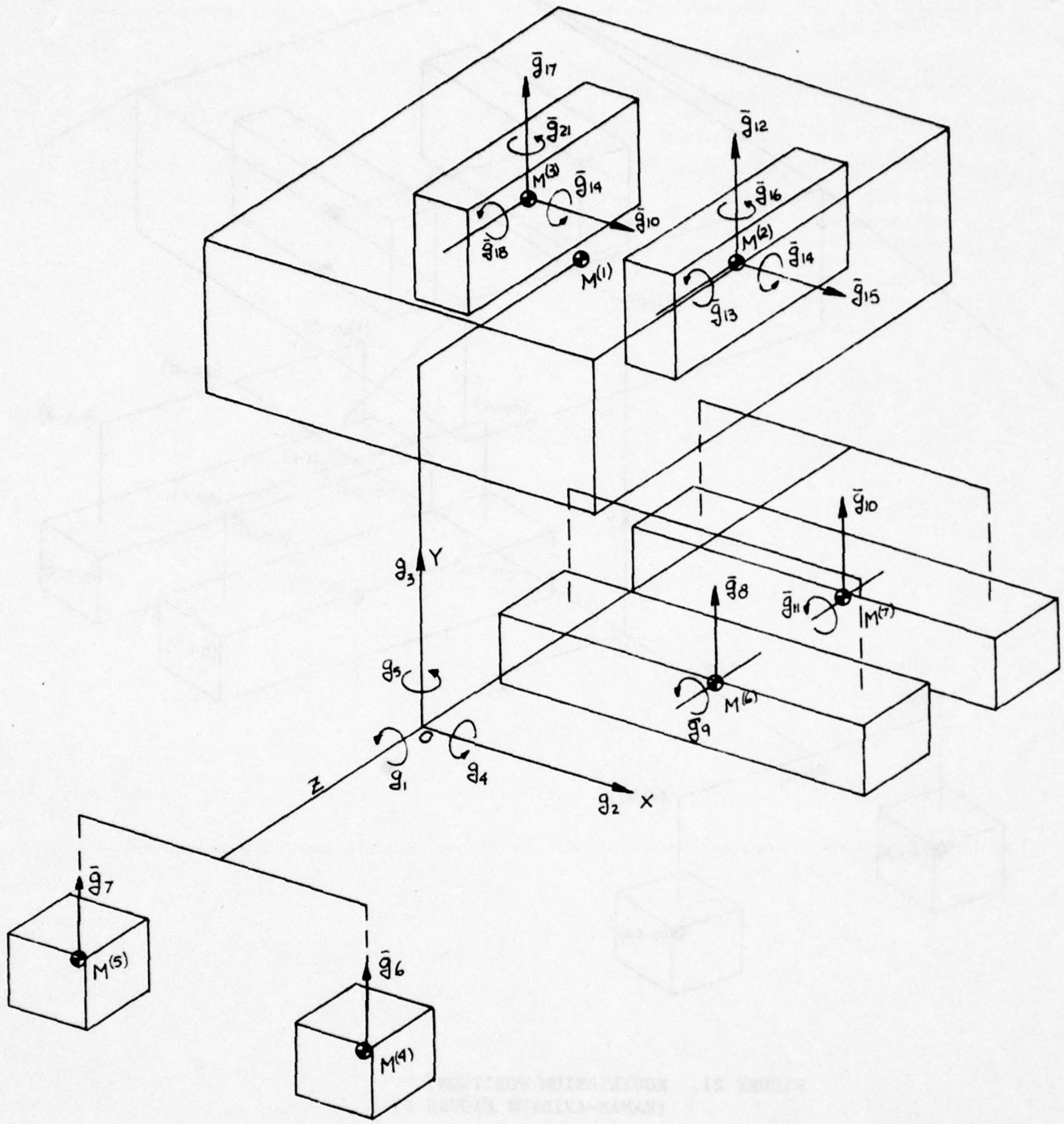


FIGURE 20. GENERALIZED COORDINATES g_i (INERTIAL SYSTEM) AND $\bar{g}_i$ (REFERENCE BODY SYSTEM).
(KAMAN-AVIDYNE FIGURE 3)

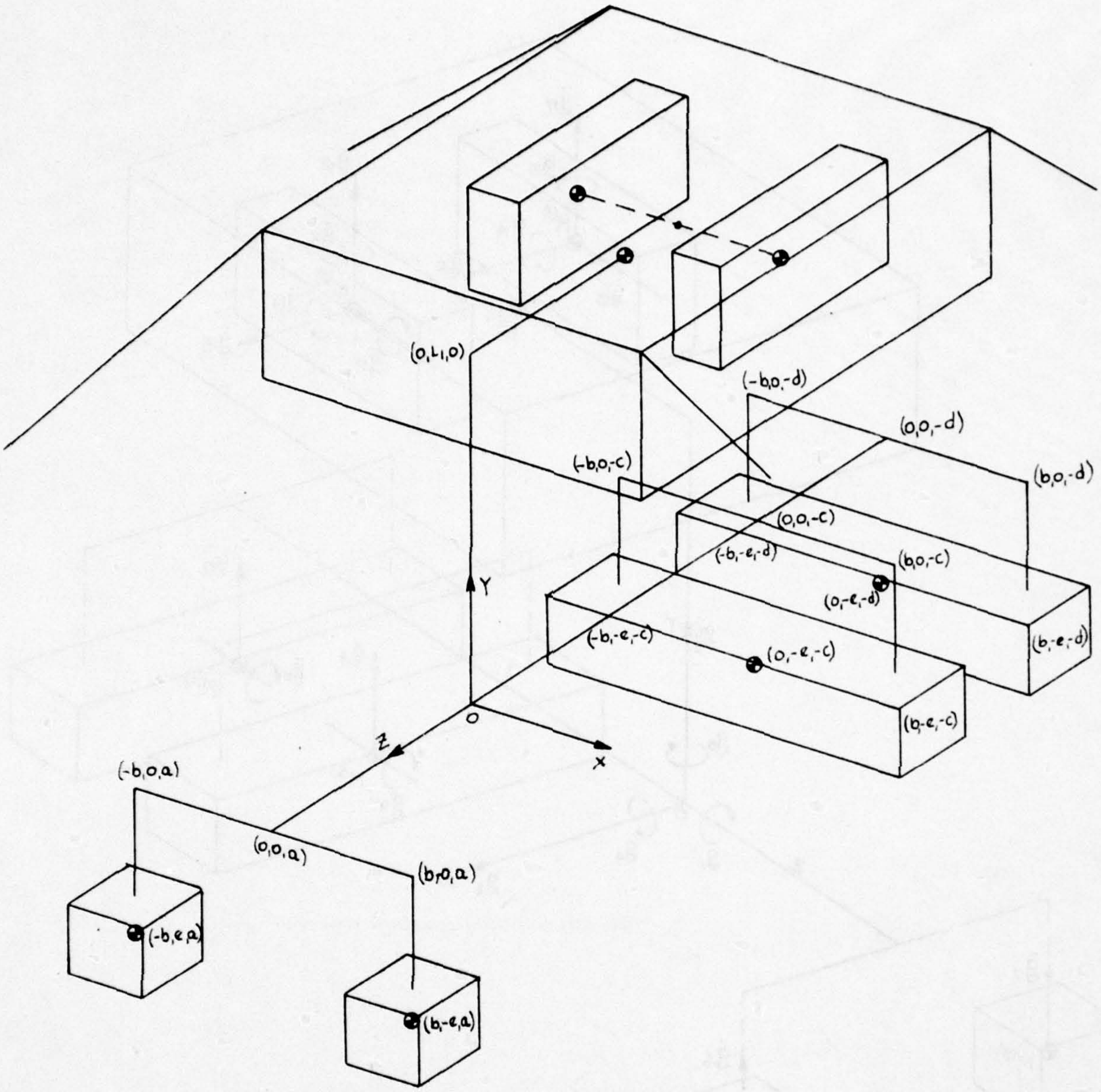


FIGURE 21. EQUILIBRIUM POSITION.
(KAMAN-AVIDYNE FIGURE 4)

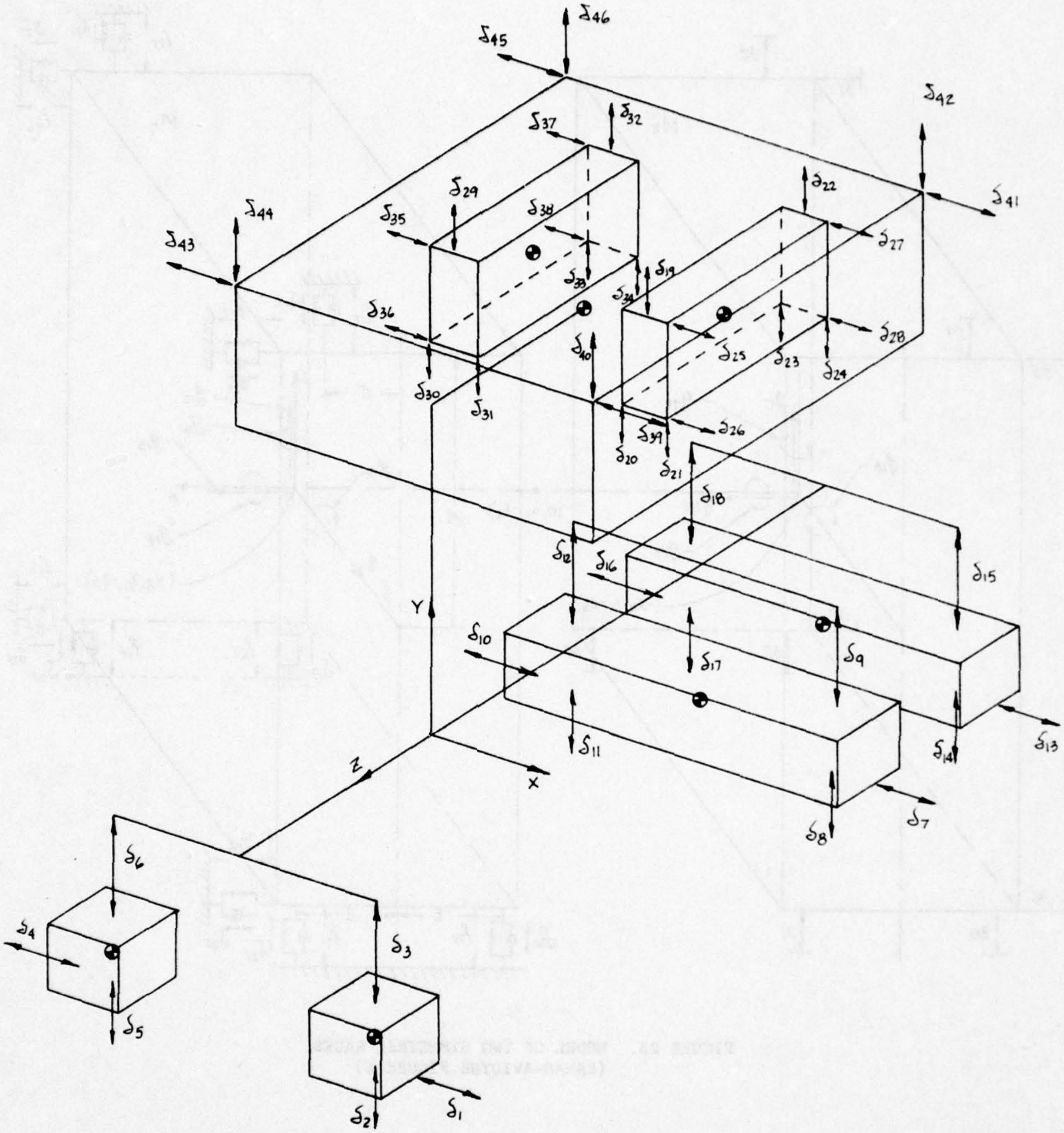


FIGURE 22. DISPLACEMENTS OF THE TOTAL SYSTEM.
(KAMAN-AVIDYNE FIGURE 5)

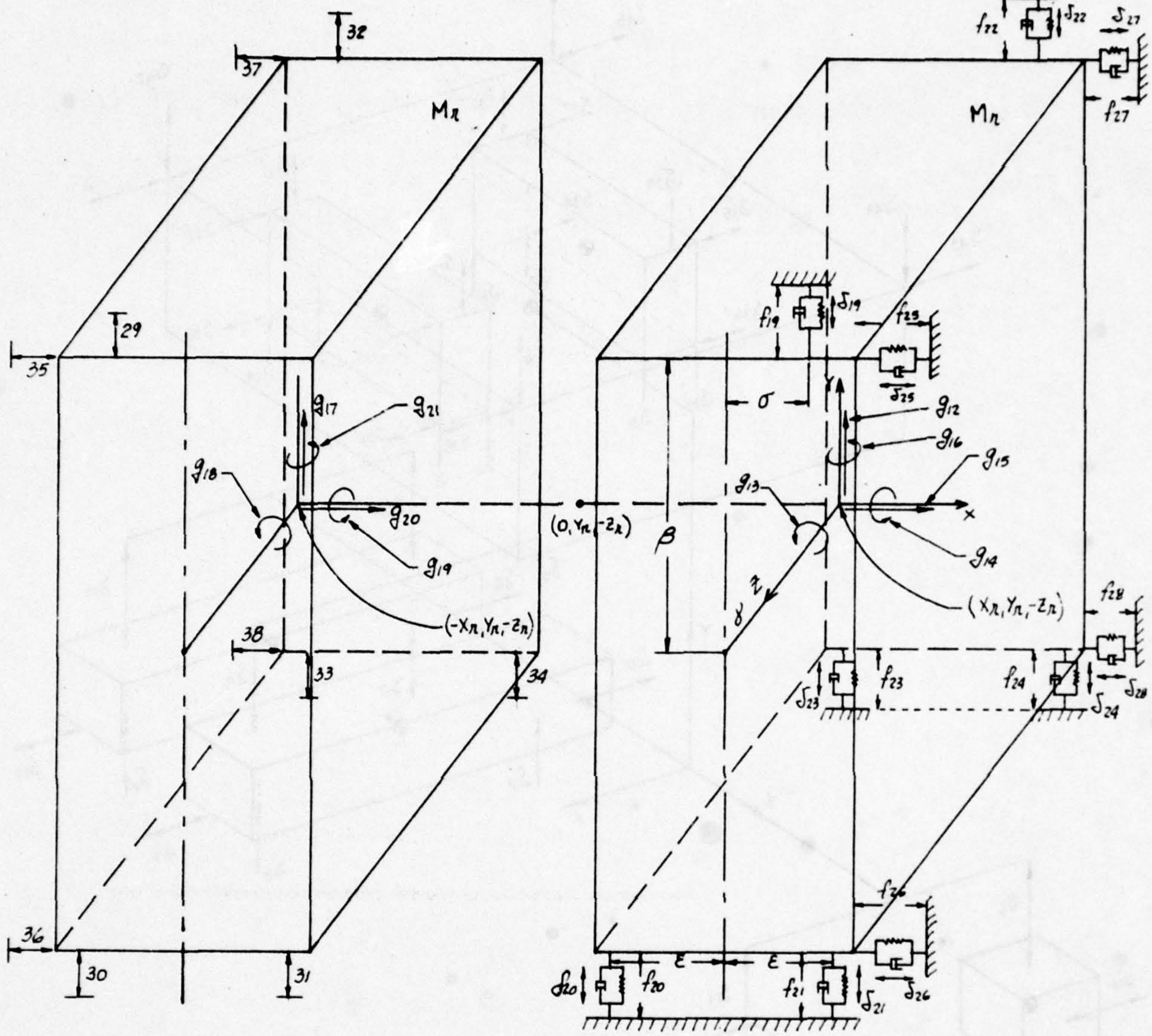


FIGURE 23. MODEL OF TWO SYMMETRIC RACKS.
(KAMAN-AVIDYNE FIGURE 6)

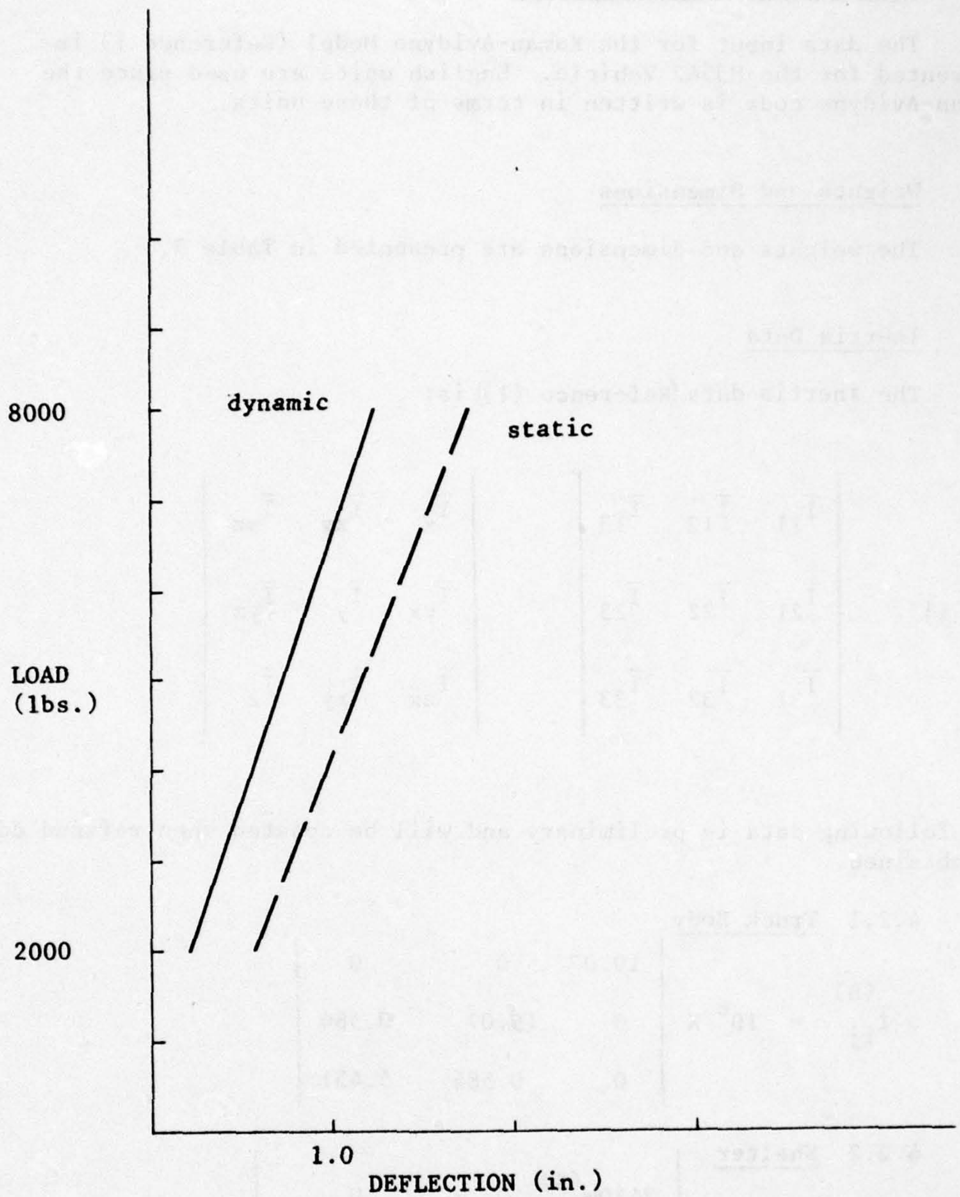


FIGURE 24: SCHEMATIC COMPARISON OF STATIC AND DYNAMIC LOAD-DEFLECTIONS OF TIRES

4.0 INPUT DATA FOR M35A2 VEHICLE

The data input for the Kaman-Avidyne Model (Reference 1) is presented for the M35A2 Vehicle. English units are used since the Kaman-Avidyne code is written in terms of these units.

4.1 Weights and Dimensions

The weights and dimensions are presented in Table 7.

4.2 Inertia Data

The inertia data (Reference (1)) is:

$$\bar{I}_{ij} \quad \begin{vmatrix} \bar{I}_{11} & \bar{I}_{12} & \bar{I}_{13} \\ \bar{I}_{21} & \bar{I}_{22} & \bar{I}_{23} \\ \bar{I}_{31} & \bar{I}_{32} & \bar{I}_{33} \end{vmatrix} = \begin{vmatrix} \bar{I}_{x} & \bar{I}_{xy} & \bar{I}_{xz} \\ \bar{I}_{yx} & \bar{I}_{y} & \bar{I}_{yz} \\ \bar{I}_{zx} & \bar{I}_{zy} & \bar{I}_{z} \end{vmatrix}$$

The following data is preliminary and will be updated when refined data is obtained.

4.2.1 Truck Body

$$\bar{I}_{ij}^{(B)} = 10^{6} \times \begin{vmatrix} 19.07 & 0 & 0 \\ 0 & 19.07 & 0.584 \\ 0 & 0.584 & 5.451 \end{vmatrix}$$

4.2.2 Shelter

$$\bar{I}_{ij}^{(S)} = \begin{vmatrix} 2430w^{(S)} & 0 & 0 \\ 0 & 2430^{(S)} & 0 \\ 0 & 0 & 1600w^{(S)} \end{vmatrix}$$

4.2.3 Left and Right Electronic Component Racks

$$\bar{I}_{ij}^{(2)} = \bar{I}_{ij}^{(3)} = \left| 0 \right|$$

4.2.4 Front Wheels and Axle

$$\bar{I}_{ij}^{(4)} = 9.765 \text{ X } 10^5 \text{ X } \begin{vmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{vmatrix}$$

4.2.5 Rear-Axles, Wheels, and Spring Systems

$$\bar{I}_{ij}^{(6)} = \bar{I}_{ij}^{(7)} = 2.984 \text{ X } 10^6 \text{ X } \begin{vmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{vmatrix}$$

4.3 Input Data for Spring-Shock Absorbers and Terrain-Tire Interactions

The following data is preliminary. Any refined data that may be obtained will be presented in a supplemental report.

4.3.1 Springs

The Load-Deflection Relation for the leaf springs in the M35A2 as well as in the M715 and M38A1 vehicles is non-linear and can be approximated by piece-wise linear relations. As discussed earlier, the relation could be sensitive to a number of parameters and has a hysteresis which could be significant. The hysteresis is neglected in the Kaman-Avidyne program. Their program considers the unloading curve to be the same as the loading curve. The maximum loads per front and aft spring are 7,500 and 17,000 lbs., respectively, for the M35A2 vehicle. The following data are for new springs.

4.3.1.1 Front Springs

The front springs for an M35A2 vehicle are of the 12-leaf type and they have been in production since 1963.

The spring rate of deflection for unclamped condition is 1110 lbs./in. for a load of 3150 lbs.. The rate of deflection for a clamped condition will be higher by the order of 10%. The piece-wise linear relation is as follows:

In compression,

$L_y = 4800\,\delta_y$, for $0 \leq \delta_y \leq 1/8$;

$L_y = 1110\,\delta_y + 460$, for $1/8 \leq \delta_y \leq 3.0$;

$L_y = 1800\,\delta_y - 1610$, for $3.0 \leq \delta_y \leq 5.2$.

The spring bottoms-out on the order of 5.5 inches.

In tension,

$L_y = 900\,\delta_y$ for $0 \geq \delta_y$.

4.3.1.2 Rear Springs

The rear springs for a M35A2 vehicle are of the 10-leaf configuration. They have been in production since 1952.

The spring rate of deflection at 4500 lbs. is 2405 lbs./in. and 2150 lbs./in. for the clamped and unclamped conditions, respectively. The linear piece-wise relation is as follows:

In compression,

$L_y = 5600\,\delta_y$, for $0 \leq \delta_y \leq 1/8$;

$L_y = 2400\,\delta y + 400$, for $1/8 \leq \delta_y \leq 2.5$;

$L_y = 3600\,\delta_y - 2600$, for $2.5 \leq \delta_y \leq 4.5$.

The spring bottoms-out on the order of 4.5 inches.

In tension,

$L_y = 1500\,\delta_y$, for $0 \geq \delta_y$.

4.3.2 Tires

The tires on a M35A2 vehicle are of 9:00-20 size and are pressurized to 45 psi. As discussed earlier the Load-Deflection Relations are sensitive to a number of parameters. The vertical and lateral Load-Deflection relations are non-linear and are represented here as a piece-wise linear function as follows:

4.3.2.1 Vertical Load-Deflection Relation

$L_y = 640\ \delta_y$, for $0 \leq \delta_y \leq 1/8$.

$L_y = 3200\ \delta_y - 320$, for $\delta_y \geq 1/8$.

4.3.2.2 Lateral Load-Deflection Relation

$L_y = 260\ \delta_x$, for $0 \leq \delta_x \leq 1/8$.

$L_y = 1280\ \delta_x - 127.5$, for $\delta_x \geq 1/8$.

4.3.3 Shock Absorbers

The shock absorbers, like the springs and tires, depend upon a number of parameters. However the rate of change for new shock absorbers is less than that of springs.

The rebound and compression characteristics of new shock absorbers are presented in Figure 25. They are presented here in terms of linear piece-wise expressions as follows:

4.3.3.1 Load-Velocity Relation in Compression

$L = 35\ \dot{\delta}$, for $0 \leq \dot{\delta} \leq 5$ in./sec.

$L = 2.6\ \dot{\delta} + 162$, for $5 \leq \dot{\delta}$.

4.3.3.2 Load-Velocity Relation in Rebound

$L = 65\ \dot{\delta}$, for $0 \geq \dot{\delta} \geq -5$ in./sec.

$L = 7.3\dot{\delta} - 288.4$, for $-5 \geq \dot{\delta}$.

4.3.4 Damping Characteristics of Springs, Tires, and Shock Absorbers

The damping characteristics of the tires are like 1/10 of the shock absorbers. The damping characteristics of the springs are of the order of 1/4 of those of the shock absorber.

4.3.5 Tire-Terrain Interaction

The data for the tire-terrain interaction depends on the geographical location of the vehicle at the time of the vehicle-blast interaction. It is known, for instance, that the coefficient of friction could vary from 0 to 0.9 for off-road conditions. The coefficient of friction for tire-asphalt and tire-concrete varies, typically, from 0.75 to 0.9 and 0.8 to 0.85, respectively.

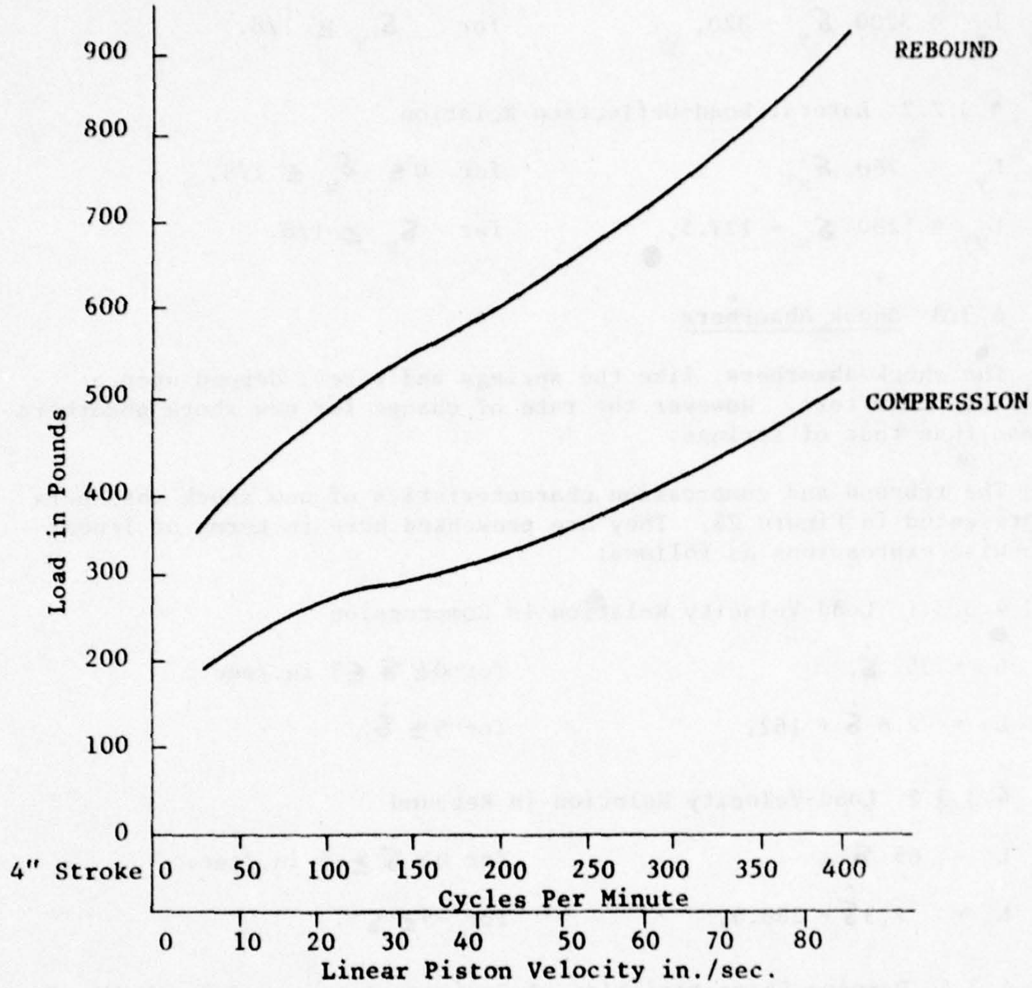


FIGURE 25: REBOUND AND COMPRESSION CHARACTERISTICS OF SHOCK ABSORBER FOR M35A2

(TOLERANCE ± 15% AT ROOM TEMPERATURE)

TABLE 7. MODEL MASSES (REFERENCE 1) AND CORRESPONDING POSITIONS WITH RESPECT TO CENTER LINE OF FRONT AXLE FOR THE M35A2 TRUCK, EMPTY CONDITION

MASS, M_i		POSITION WITH RESPECT TO THE C.L. OF FRONT AXLE					
i	Weight	X	Y	(-)Z	X	Y	(-)Z
Fig.3	lbs.	Dim. inches	Dim. inches	Dim. inches	Dim. inches	Dim. inches	Dim. inches
1	8721	0.0	20.0	70.0			
** 1c	2200	0.0	22.0	60.0			
1e	1350	0.0	22.38	0.0			
1f	5171	0.0	17.0	80.0			
M^S	U ***						
2	U						
3	U						
4	1411	0.0	0.0	0.0			
4a	840	0.0	0.0	0.0			
4w	200	33.874	0.0	0.0	33.874	-19.1	0.0
4sp	76.5	15.4	5.6	0.0	15.4	10.8	0.0
4sh	9	15.4	-1.4	3.24	15.4	11.19	10.76
5	omitted						
6	1634						
6a	750	0.0	0.0	130			
6w	400	35	0.0	130	35	-19.1	130
6sp	84	20.24	2.57	154	20.24	11.54	154
6sh	none						
7	1634						
7a	750	0.0	0.0	178			
7w	(Continued on next page)						

TABLE 7. (Continued)

MASS, M_i		POSITION WITH RESPECT TO THE C.L. OF FRONT AXLE					
i	Weight	X	Y	(-)Z	X	Y	(-)Z
Fig.3	lbs.	Dim. inches	Dim. inches	Dim. inches	Dim. inches	Dim. inches	Dim. inches
7w	400	35	0.0	178	35	-19.1	0.0
7sp	84	20.24	2.57	154	20.24	11.54	154
7sh	none						

* The minus sign (-) in front of Z implies that the Z-axis is positive when measured from the C.L. of the axle towards the front of the vehicle.

** 1c denotes the cab of the vehicle.
1e " " engine of the ".
1f " " frame " " ".
4a " " front axle.
4w " " " wheel.
4sp " " " spring.
4sh " " " shock absorber.
6a " " " axle of the bogie.
6w " " " wheels " "
6sp " " aft spring
6sh " " " shock absorber (and there are none).
7a " " " axle of the bogie.
7w " " " wheels of the ".
7sp " " " spring and is the same as 6sp.
7sh " " " shock absorber (and there are none).

*** U means unknown.

5.0 INPUT DATA FOR M715 VEHICLE

The data input for the Kaman-Avidyne Model for the M715 vehicle is presented in this section. English units are used since the Kaman-Avidyne code is written in terms of such units.

5.1 Weights and Dimensions

The weights and dimension for the M715 vehicle are presented in Table 8.

5.2 Inertia Data

The inertia data, using the notation in Reference 1 presented in section 4.0 for the M35A2 vehicle, is as follows for the M715 vehicle:

5.2.1 Truck Body

$$\bar{I}_{ij}^{(B)} = 10^6 \times \begin{vmatrix} 6.301 & 0 & 0 \\ 0 & 6.301 & 0.0952 \\ 0 & 0.0952 & 1.949 \end{vmatrix} .$$

5.2.2 Shelter

The data for the shelter to be placed on the M715 was not available for this report.

5.2.3 Left and Right Electronic Component Racks

$$\bar{I}_{ij}^{(2)} = \bar{I}_{ij}^{(3)} = 0 .$$

5.2.4 Front Wheels and Axle

$$\bar{I}_{ij}^{(4)} = 10^6 \times \begin{vmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{vmatrix} .$$

5.2.5 Rear Axle and Wheel System

$$\bar{I}_{ij}^{(6)} = 1.065 \times \begin{vmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{vmatrix} \times 10^6 .$$

$$\bar{I}_{ij}^{(7)} = \left| 0 \right| .$$

5.3 Input Data for Springs, Tires, and Shock Absorbers

The following data for the Load-Deflection Relations for the springs and tires as well as the Load-Velocity Relation for the shock absorbers are preliminary. Any further refined data will be presented at a later date.

5.3.1 Load-Deflection Relation for the Springs

The front and rear springs have seven leaves, but have different spring constants in the linear range. The relations are non-linear and are represented by piece-wise linear relations.

5.3.1.1 Front Springs

The maximum load for the front springs, i.e. per spring, is 3,500 lbs.. The relation for compression is:

$$L_y = 2000\ \delta_y, \qquad \text{for } 0 \leq \delta_y \leq 1/8;$$

$$L_y = 515\ \delta_y + 186, \qquad \text{for } 1/8 \leq \delta_y \leq 3;$$

$$L_y = 800\ \delta_y - 669, \qquad \text{for } 3 \leq \delta_y \leq 8.3 .$$

The spring bottoms-out on the order of 8.5 .

The relation for the spring in tension is:

$$L_y = 300\ \delta_y .$$

5.3.1.2 Rear Springs

The maximum load for each spring is 5,400. The relation for compression is:

$$L_y = 2400\ \delta_y, \qquad \text{for } 0 \leq \delta_y \leq 1/8;$$

$$L_y = 715\ \delta_y + 211, \qquad \text{for } 1/8 \leq \delta_y \leq 3;$$

$$L_y = 1100\ \delta_y - 944, \qquad \text{for } 3 \leq \delta_y \leq 6.2 .$$

The spring bottoms out on the order of 6.5 inches.

The relation for the spring in tension is:

$$L_y = 500\ \delta_y .$$

5.3.2 Load-Deflection Relations for the Tires

The tires on the M715 vehicle are size 9:00-16. The front tires are inflated to 25 psi, while the rear ones are inflated to 45 psi.

5.3.2.1 Vertical Load-Deflection Relation

The relation for the front tire is:

$$L_y = 420\,\delta_y, \qquad \text{for} \quad 0 \le \delta_y \le 1/8;$$

$$L_y = 2100\,\delta_y - 210, \qquad \text{for} \quad \delta_y \ge 1/8.$$

The relation for the rear tire is:

$$L_y = 600\,\delta_y, \qquad \text{for} \quad 0 \le \delta_y \le 1/8;$$

$$L_y = 3000\,\delta_y - 300, \qquad \text{for} \quad \delta_y \ge 1/8.$$

5.3.2.2 Lateral Load-Deflection Relation

$$Lx = 170\,\delta_x, \qquad \text{for} \quad 0 \le \delta_x \le 1/8;$$

$$L_x = 1240\,\delta_x - 123.75, \qquad \text{for} \quad \delta_x \ge 1/8.$$

The relation for the rear tire is:

$$L_x = 240\,\delta_x, \qquad \text{for} \quad 0 \le \delta_x \le 1/8;$$

$$L_x = 1200\,\delta_x - 120, \qquad \text{for} \quad \delta_x \ge 1/8.$$

5.3.3 Load-Velocity Relation for Shock Absorbers

The compression and rebound characteristics of the M715 shock absorbers in terms of linear piece-wise expressions are as follows:

5.3.3.1 Front Shock Absorbers

In compression:

$$L = 21.7\,\dot{\delta}, \qquad \text{for} \quad 0 \le \dot{\delta} \le 4.7;$$

$$L = 10\dot{\delta} + 55, \qquad \text{for} \quad 4.7 \le \dot{\delta} \le 13.3;$$

$$L = 3.83\dot{\delta} + 137.1, \qquad \text{for} \quad 13.3. \le \dot{\delta}.$$

In rebound:

$L = 48.1\,\dot{\delta},$ for $0 \geq \dot{\delta} \geq -4.7;$

$L = 6.39\,\dot{\delta} - 210,$ for $-4.7 \geq \dot{\delta}.$

5.3.3.2 Aft Shock Absorbers

In compression:

$L = 7.8\,\dot{\delta},$ for $0 \leq \dot{\delta} \leq 13.3;$

$L = 3.09\,\dot{\delta} + 61.9,$ for $13.3 \leq \dot{\delta}.$

In rebound:

$L = 27.7\,\dot{\delta},$ for $0 \geq \dot{\delta} \geq -4.7;$

$L = 5.36\,\dot{\delta} - 104.8,$ for $-4.7 \geq \dot{\delta}.$

TABLE 8. MODEL MASSES AND CORRESPONDING POSITIONS WITH RESPECT TO CENTER LINE OF FRONT AXLE FOR THE M715 TRUCK, EMPTY CONDITION (SEE TABLE 7 FOR NOMENCLATURE)

MASS ,M_i		POSITION WITH RESPECT TO THE C.L. OF FRONT AXLE					
i	Weight	X	Y	(-)Z	X	Y	(-)Z
	lbs.	Dim. inches	Dim. inches	Dim. inches	Dim. inches	Dim. inches	Dim. inches
1	4026	0.0	15.5	55			
1c	1100	0.0	16	50			
1e	850	0.0	14.2	6.66			
1f	2076	0.0	10	65			
M^S	U						
2	U						
3	U						
4	737.2	0.0	0.0	0.0			
4a	350	0.0	0.0	0.0			
4w	137.5	37.5	0.0	0.0	37.5	17	0.0
4sp	50.1	17.8	1.28	0.0	25.13	9.78	0.0
4sh	6	17.8	-2.07	3.07	17.8	15.52	3.07
5	omit						
6	736.96						
6a	315	0.0	0.0	126			
6w	137.5	37.5	0.0	126	37.5	17	126
6sp	66.98	25.13	4.61	126	25.13	11.11	126
6sh	6.5	18.32	-3.10	128.05	18.32	10.86	137.26

6.0 INPUT DATA FOR M38A1 VEHICLE

The data input for the Kaman-Avidyne Model for the M38A1 vehicle is presented in this section. English units are used since the Kaman-Avidyne code is written in terms of such units.

6.1 Weights and Dimensions

The weights and dimensions for the M38A1 vehicle are presented in Table 9.

6.2 Inertia Data

Using the notation used for the M35A2 and M715 vehicles in the previous sections, the inertia data for the M38A1 are as follows:

6.2.1 Truck Body

$$\bar{I}_{ij}^{(B)} = 10^6 \times \begin{vmatrix} 11.852 & 0 & 0 \\ 0 & 11.852 & 0.01284 \\ 0 & 0.01284 & 0.7012 \end{vmatrix}$$

6.2.2 Shelter

No shelter will be placed on the M38A1 vehicle.

6.2.3 Electronic Racks

There are no racks on the M38A1 vehicle.

6.2.4 Front Wheels and Axle

$$\bar{I}_{ij}^{(4)} = 3.233 \times 10^5 \times \begin{vmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{vmatrix}$$

6.2.5 Rear Axle and Wheels

$$\bar{I}_{ij}^{(6)} = 3.480 \times 10^5 \times \begin{vmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{vmatrix}$$

6.3 Input Data for M38A1 Springs, Tires, and Shock Absorbers

The following data are preliminary:

6.3.1 Load-Deflection Relations for the Springs

The front and rear springs have 12 and 13 leaves, respectively. The Load-Deflection Relations are represented by linear piece-wise expressions as follows:

6.3.1.1 Front Springs

The maximum load for each of the front springs is 1700 lbs.. The relation for compression is:

$$L_y = 800\ \delta_y, \qquad \text{for} \quad 0 \leq \delta_y \leq 1/8;$$

$$L_y = 230\ \delta_y + 71, \qquad \text{for} \quad 1/8 \leq \delta_y .$$

The spring bottoms-out on the order of 1.5 inches. The relation for tension is:

$$L_y = 100\ \delta_y .$$

6.3.1.2 Rear Springs

The maximum load for each of the rear springs is 2100 lbs.. The relation for compression is:

$$L_y = 640\ \delta_y, \qquad \text{for} \quad 0 \leq \delta_y \leq 1/8;$$

$$L_y = 200\ \delta_y + 72, \qquad \text{for} \quad 1/8 \leq \delta_y \leq 3;$$

$$L_y = 320\ \delta_y - 288, \qquad \text{for} \quad 3 \leq \delta_y \leq 5.2 .$$

The spring bottoms-out on the order of 5.5 inches. The relation for tension is:

$$L_y = 90\ \delta_y .$$

6.3.2 Load-Deflection Relations for the M38A1 Tires

The tires on the M38A1 vehicle are size 7:00-16, and they are inflated to 25 psi.

6.3.2.1 Vertical Load-Deflection Relation

The relation for the front and rear tires is:

$$L_y = 380\ \delta_y, \qquad \text{for } 0 \leq \delta_y \leq 1/8;$$

$$L_y = 1900\ \delta_y - 190, \qquad \text{for} \quad 1/8 \leq \delta_y .$$

6.3.2.2 Lateral Load-Deflection Relation

The relation for the front and rear tires is:

$L_x = 150\,\delta_x$, for $0 \leq \delta_x \leq 1/8$;

$L_x = 760\,\delta_x - 76.25$, for $1/8 \leq \delta_x$.

6.3.3 Load-Velocity Relation for M38A1 Shock Absorber

The compression and rebound characteristics of the M38A1 shock absorbers in terms of linear piece-wise expressions are as follows:

6.3.3.1 Front Shock Absorbers

In compression:

$L = 15\,\dot{\delta}$, for $0 \leq \dot{\delta} \leq 5.0$;

$L = 4\,\dot{\delta} + 55$, for $5 \leq \dot{\delta}$.

In rebound:

$L = 30\,\dot{\delta}$, for $0 \geq \dot{\delta} \geq -5.0$;

$L = 5\,\dot{\delta} - 125$, for $-5 \geq \dot{\delta}$.

6.3.3.2 Aft Shock Absorbers

In compression:

$L = 10\,\dot{\delta}$, for $0 \leq \dot{\delta} \leq 10$;

$L = 3.5\,\dot{\delta} + 65$, for $10 \leq \dot{\delta}$.

In rebound:

$L = 15\,\dot{\delta}$, for $0 \geq \dot{\delta} \geq -10$;

$L = 5\,\dot{\delta} - 100$, for $-10 \geq \dot{\delta}$.

TABLE 9. MODEL MASSES AND CORRESPONDING POSITIONS WITH RESPECT TO CENTER LINE OF FRONT AXLE FOR THE M38A1 VEHICLE, EMPTY CONDITION (SEE TABLE 7 FOR NOMENCLATURE)

MASS, M_i		POSITION WITH RESPECT TO THE C.L. OF FRONT AXLE					
i	Weight	X	Y	(-)Z	X	Y	(-)Z
	lbs.	Dim. inches	Dim. inches	Dim. inches	Dim. inches	Dim. inches	Dim. inches
1	1752	0.0	11	38			
1c	540	0.0	13	33			
1e	394	0.0	12	15			
1f	818	0.0	10	40			
			$M^{(S)}$, 2, 3 are unknown				
4	388	0.0	0.0	0.0			
4a	144	0.0	0.0	0.0			
4w	88	24.56	0.0	0.0	24.56	-15	0.0
4sp	26	12.5	-1.0	0.0	12.5	1.25	0.0
4sh	3.5	15	-4.0	-2	15	9.5	-6.5
5	omit						
6	384						
6a	116	0.0	0.0	81			
6w	93	24.6	0.0	81	24.6	-15	81
6sp	38	12.5	-1.8	81	12.5	1.5	81
6sh	3.8	15	-4.5	77.5	15	10	70.5
7	omit						

7.0 ISSUES AND NEEDS

Since there is an apparent lack of data for a dynamic analysis of the M35A2, M715, and M38A1 vehicles, there are issues and needs that require further exploration.

7.1 Typical Issues

7.1.1 Data Variance

An issue that requires further exploration is the variance of data from one vehicle to another. For instance: Do the springs vary by 5% or is it likely to be by 25% or more?

7.1.2 Springs as a Single Beam

Do the leaf springs behave like a single beam or is there sufficient freedom between the leafs to give sufficient sliding for a true spring action?

7.1.3 Frame as a Torque Bar and Spring

Another issue is whether the frame and the drive train (due to their length and flexibility) under the blast loading act as a torque bar (hence a possible spring action) and do not act as a lump mass as assumed in the dynamic model.

7.2 Needs (Analytical and Test)

7.2.1 Springs

7.2.1.1 Front and Rear Wheel Suspension Spring Rates

There is a need to determine, by testing and analysis, the spring-deflection curve of several springs of vehicles that have been in use for several thousand miles and more.

These data should then be compared with those of new springs to determine the variance and the possible behavior of the old springs in the manner of a single beam. (Figure 26)

Also, load deflection tests should be conducted to obtain both the vertical and lateral spring rates of the bogie suspension system. The effects of the tie and torque rods must be included in the determination of the transverse spring rates.

7.2.1.2 Front and Rear Tire Spring Rates and Damping Characteristics

The spring rates of the tires must be determined experimentally. Again, the effects of age and wear of tire as well as the terrain must be considered. These data should be obtained experimentally.

7.2.2 Shelter-Frame Interaction

These data should be obtained by either test and/or analysis and only after the interface between the shelter and the rest of the vehicle is defined. The analysis or test should include any clamps as well as the effect of any preloaded tie-down wires.

7.2.3 Frame and Drive Train

Since the vehicle is subjected to a side-on blast wave, the frame and drive train, compared to the engine and the axle frame, are long and thin and could behave like a series of torque and tie rods. These torque and tie rods could be considered as thin beams that give a spring-like action to the spring-mass system. These effects should also be investigated analytically and experimentally.

7.2.4 Weights, Dimensions, and Inertias

There is a need to determine the weight, dimensions, and inertias of the engine, the frame and drive train, and the cab.

7.2.5 Dynamic Modeling

The dynamic model in Reference 1 does not appear to be adequate enough to accommodate the apparent variations in the data. There is a need to review the adequacy of the dynamic model in Reference 1 relative to the parameters specified in this report.

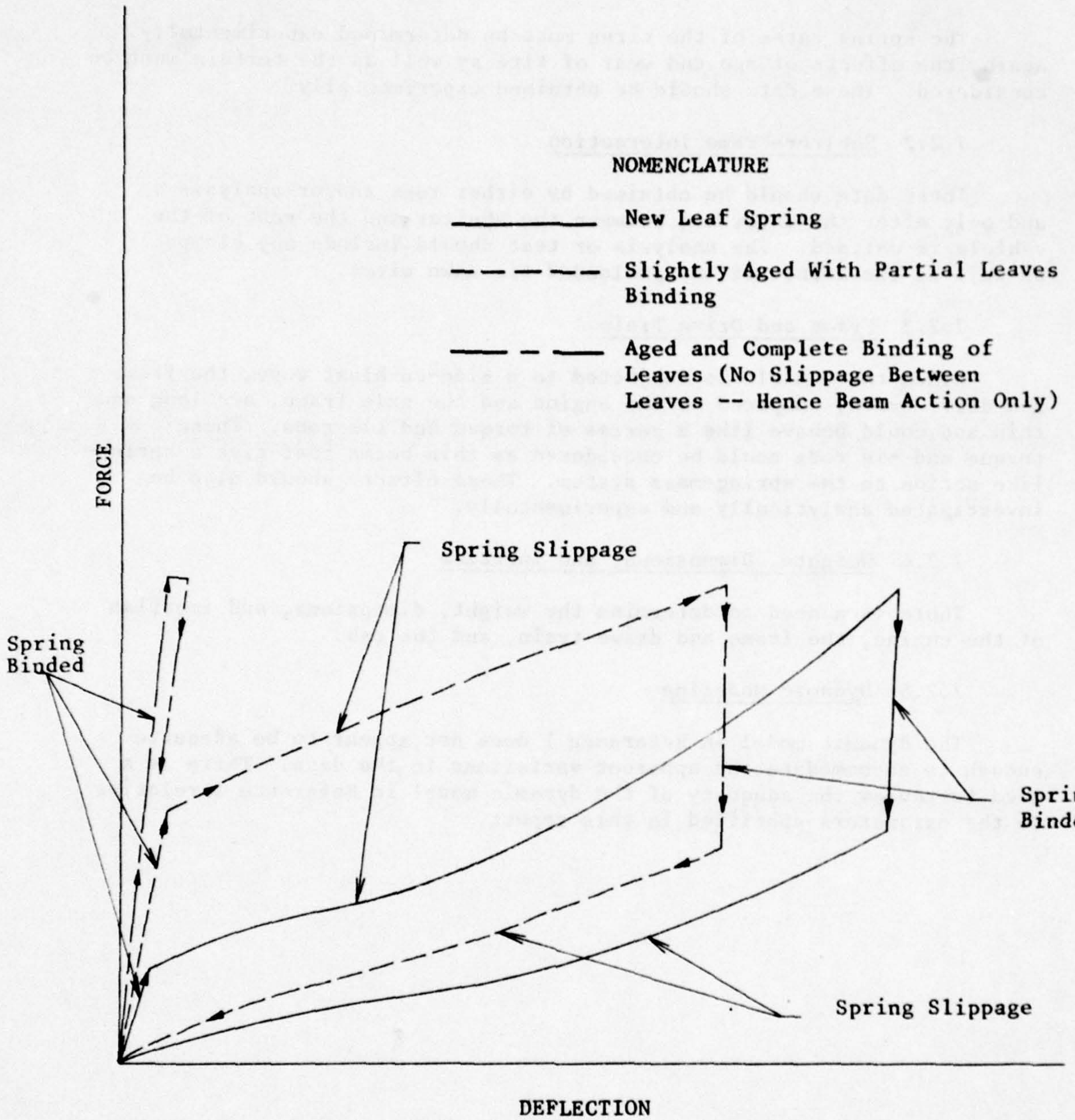


FIGURE 26: SCHEMATIC OF COMPARISON OF FORCE-DEFLECTION CURVE FOR NEW AND AGED SPRINGS

8.0 DETERMINATION OF WEIGHTS, CENTERS OF GRAVITY (CG), AND INERTIAS OF VEHICLES

8.1 Weight of Vehicle

The weight, W_v, of the vehicle is determined by placing a certified scale, with accuracy within 0.5 pound, under each wheel. All wheels, including those on the scale, should be on the same horizontal plane. The total weight of the vehicle is determined by adding the four weights determined under each wheel, as illustrated in Table 10.

The vehicle weighed was an M38A1 Army Willys Jeep, Serial Number 20999491. The Jeep was in a parked condition for a number of months at the Defense Property Disposal Office located at Norton Air Force Base, California. The vehicle was inoperable and had no fuel or water in its test configuration. It also had no spare wheel, repair tools, rear seat, pin bolts, canvas top, tail pipe extension, and possibly, other minor parts. It did have oil in its engine.

8.2 Position of Center of Gravity (C.G.)

8.2.1 Longitudinal and Lateral Positon of CG

The longitudinal and lateral position of the CG is determined by trial and error with two steel knife edges (T-Beam) and supported by two jack stands. The longitudinal and lateral CG axes are marked on the frame of the vehicle, and the intersection of the two axes is marked on the skid plate beneath the vehicle and near the gear shift stick in the vehicle as illustrated in Figure 27.

8.2.2 Height of CG

The following steps were taken to determine the CG height:

a. The knife edges located on two jack stands are used to support the vehicle laterally. The rear of the vehicle is resting on a horizontal surface.

b. A horizontal reference line is determined and marked with a carpenter's level on the vehicle. (An inclinometer could be used in place of the level.) This tilt position was chosen because it is impossible to balance the vehicle in a horizontal position on the knife edges for the subsequent test procedures. A fraction of a pound is enough to tilt it from a horizontal position. The horizontal line determined by the level could be used for measuring distances and angles of rotation about the knife edges. The angle between the fore and aft axis of the CG and the horizontal*line could be used as a reference or initial angle

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* The vehicle is in a balanced and near horizontal position, i.e. the longitudinal CG axis is nearly horizontal.

but the weight of the rear portion of the vehicle in its test configuration is extremely difficult to determine. So, instead, the initial* angle,with its corresponding weight,will be defined and determined in the subsequent paragraphs. The angle, weight, and distance from the knife edges,along with the vehicle weight, will be used in the sum of the moments to determine the height of the CG as illustrated in Figure 27.

c. The rear of the vehicle is to be raised from its tilted position by a hydraulic jack placed upon a certified scale. The jack is placed just beneath the intersection of the rear lateral member of the frame and the longitudinal (fore-aft) axis of the CG. The hydraulic jack and the other materials used to raise the vehicle are weighed before the rear of the vehicle is raised.

d. The vehicle is raised until the tires are just above the position of barely touching the floor. This position should be close to the maximum weight reading for the vehicle in its test configuration. At this position, a horizontal line (level) is drawn on the vehicle. The angle between this horizontal and the CG axis will be called θ_1 and the corresponding weight W_1. Since it is impossible to place the vehicle's longitudinal axis into a horizontal position, an initial angle will be defined as θ_o and is determined in subsequent formulas.

e. The vehicle is further raised by the hydraulic jack and a new reading is recorded for the weight and the angle of rotation about the lateral CG axis. These readings are continued until the vehicle's longitudinal CG axis reaches its horizontal position and any further raising of the jack will cause the vehicle to tilt forward.

f. The height of the CG above the knife edge support is then determined by summing the moments about the lateral knife edge support. Letting:

H_o = height of CG above edge;
W_v = weight of vehicle;
W_i = weight recorded on scale less weight of jack and other materials on scale, i = 1,2,3,4,...,n;
θ_i = angle of rotation of vehicle about knife edge due to W_i;
L^i = distance of W_i position (on rear frame) from the knife edge and measured along the longitudinal CG axis of vehicle;
θ_o = angle of inclination of vehicle when longitudinal axis is nearly horizontal,

then the sum of the moments about the lateral knife edge for the weight W_i is:

---

* The vehicle is in a balanced and near horizontal position, i.e. the longitudinal CG axis is nearly horizontal.

$$W_v H_o \sin(\theta_i - \theta_o) = W_i L \cos(\theta_i - \theta_o)$$

or:

$$1/H_o = (W_v / LW_i) \tan(\theta_i - \theta_o) .$$

Since the angle of rotation θ_o is difficult to determine it is considered as a variable to be determined along with H_o. This requires two equations for determining H_o and Θ_o as follows:

$$1/H = (W_v / LW_i) \tan(\theta_i - \theta_o)$$

and:

$$1/H = (W_v / LW_j) \tan(\theta_j - \theta_o) .$$

Choosing two sufficiently different readings for W_i and W_j, and eliminating H_o between the two equations, gives:

$$W_i / W_j = \tan(\theta_i - \theta_o) / \tan(\theta_j - \theta_o) .$$

θ_o is then determined by trial and error. A solution for H_o is then determined by substituting θ_o back into either equation for H_o.

g. A check on the accuracy of the determined H_o may be made by using another weight W_k, preferably between W_i and W_j.

8.3 Total Vehicle Moments of Inertia

8.3.1 Rotational Moment of Inertia about the Vertical (Azimuth) Axis through the CG

Due to the large weights and varying dimensions of the vehicles, the pendulum technique is not considered to be practical because of possible inaccuracies, large overhead supporting structures, etc.. So instead, ball-bearing supports could be used under (either) all (or two) of the wheels and a central large ball-bearing pivot point just aft (or in front) of the CG. The pivot point selected is to the rear (6") of the CG point as indicated on the skid plate in Figure 28 and on the longitudinal CG axis. Two springs with known spring constants (K_1 and K_2) are attached laterally to the rear and front of the vehicle at distances L_1 and L_2 from the pivot point. The pivot point is at a distance L_3 from the CG azimuth axis. The springs are attached laterally to a fixed vertical plane (wall) near the vehicle (Figure 28). The rotational inertia can be obtained from the formula:

$$I_{az} = ((K_1 L_1^2 + K_2 L_2^2) \tau^2 / (4\pi^2)) - ((W_v L_3^2) / g)$$

where:

I_{az} = Rotational inertia around vertical (azimuth) axis;

K_1 = Spring constant of rear spring;

K_2 = Spring constant of front spring;

L_1 = Distance of rear spring from pivot point;

L_2 = Distance of front spring from pivot point;

L_3 = Distance of CG from pivot point;

τ = Period of oscillation of spring-vehicle system;

W_v = Weight of vehicle;

and g = Gravity.

The test steps are as follows:

a. Constrain suspension system to a fixed position by utilizing scissor jacks.

b. Place front (or rear or both) wheels on steel plates separated by ball-bearings. Thus front (or rear or both) wheels can move freely about the pivot point.

c. Place pivot under vehicle 6" aft of the CG. The pivot should have:

i. Ball-bearing in a bearing plate;

ii. The plate should be fixed under the ball but with sufficient diameter so that the weight of the vehicle can be distributed over a number of ball-bearings or other material that freely allows rotation of the bearing plate;

iii. Attach spring of known spring constant onto the rear and front vertical portions of the vehicle and to a fixed vertical wall near the vehicle;

iv. Rotate the vehicle through a sufficciently large amplitude (5^o) of spring-vehicle system;

and v. Measure the period of oscillation.

d. Calculate the rotational inertia for the above system.

8.3.2 Fore and Aft (Pitch) Inertia

8.3.2.1 Pendulum Technique

The fore and aft inertia can be determined by a technique analagous to that of the determination of the height of the CG. The difference is in placing the knife edge at a distance H_1 above the CG. This can be done by tying the vehicle to a lateral beam and in the same vertical plane as the CG. The knife is supported by a column or trusses on each side of the vehicle. The pitch is derived from the following equation of oscillations:

$$\frac{d^2}{dt^2}(\theta_2-\theta_1)(I_p + W_v H_1^2/g) + (\theta_2-\theta_1)(W_v H_1) = 0 \quad .$$

Letting:

$$\theta_2-\theta_1 = A_n \exp(\omega_n t)$$

and making the substitution:

$$\tau = 2\pi/\omega_n$$

and solving for I_p we get:

$$I_p = W_v H_1((\tau^2/4\pi^2) - H_1/g).$$

θ_1 is the initial angle of fore and aft rotation about the CG and 0_2 is the angular position of the vehicle

8.3.2.2 Swing Technique

Basically the swing is analogous to that of the pendulum except that the swing is supported by the knife edge at each end (or side) of the vehicle and the vehicle is completely on the swing. The prime difference is that the inertia and period of oscillation of the swing has to be included.

The swing equation of motion is:

$$\frac{d^2\theta}{dt^2}(I_s + (W_s/g)H_2^2) + \theta(W_s H_2)) = 0$$

Solving for I_s gives:

$$I_s = \frac{W_s H_2 \tau_s^2}{4\pi^2} - \frac{W_s H_2^2}{g} \quad .$$

The equation of motion for combined swing and vehicle is:

$$\frac{d^2\theta}{dt^2}\left(I_p + I_s + \frac{W_v H_1^2}{g} + \frac{W_s H_2^2}{g}\right) + \theta(W_v H_1 + W_s H_2) = 0$$

and solving for I_p yields:

$$I_p = W_v H_1 \left(\frac{\tau^2}{4\pi^2} - \frac{H_1}{g}\right) = \frac{W_s H_2}{4\pi^2}(\tau^2 - \tau_s^2) \quad .$$

Here:

τ = Period of oscillation of swing and vehicle; and

τ_s = Period of oscillation of swing only.

8.3.2.3 Spring-Mass Technique for Inertia Measurements

A technique similar to the rotational inertia and location of the height of CG may be used. This involves using either the knife edge or the ball-bearing at a distance L_3 from the CG as a pivot point and placing two springs vertically on the fore and aft CG axis at distances L_2 (front bumper) and L_1 (rear bumper) from the pivot point. Inertia relations may be obtained for this technique and will be developed at a later time.

8.3.3 Side Roll Moment of Inertia

The three techniques discussed for determining the fore and aft moment of inertia (I_p) may be used for the side roll moment of inertia (I_r). Here I_p would be replaced by I_r in the relations for I_p.

TABLE 10. WEIGHT OF ARMY WILLYS JEEP NO. 20999491

(The scale* used is a Fairbank Morse Beam scale rented from the Riverside Scale Co.. It is certified up to 1000 pounds.)

Left Front	649.5 lbs.
Right Front	748.5 lbs.
Right Rear	512.5 lbs.
Left Rear	580.0 lbs.
Vehicle Wt. (W_v)	2,490.5 lbs.

* See TABLE 11 for Preliminary Listing of Typical Test Equipment.

TABLE 11. PRELIMINARY LISTING OF TEST EQUIPMENT

1. Certified scales, weights, and angular and linear measuring devices. Cameras, stop watch, and other clocking devices for measuring oscillation and data from dynamic tests for force-deflection, force-velocity, etc..

2. Hydraulic jacks (two or more types), (two hydraulic floor jacks for raising a vehicle onto knife edges. etc.).

3. Jack stands (four or more).

4. Scissor jacks (four).

5. Knife edges (two).

6. Level, straight edge, and markers.

7. Steel plates.

8. Ball bearings: 3/16, 7/16, 11/16, and 15/16 inches in diameter.

9. Rectangular plates 0.5 inches thick with bearing (partial) seats at the center for bearing of 11/16 inches in diameter. This plate will be attached by clamps to bottom of vehicle.

10. Rectangular plates with bearing (partial) seat on one side for the 11/16 inches diameter bearing. On the other side one (or two) circular race track(s) for 3/16 or 7/16 inches bearings. (Note: the race track may not be needed.)

11. Rectangular plate with bearing race track(s) to match the one mentioned in 10. (Note: the race track(s),and hence this plate may not be needed.)

12. A stand or blocks to support the vehicle through the bearing plates listed in 10 and 11.

13. Coil springs with known spring constants that match the force to be applied in the inertia tests. Two springs for each type of tests.

14. A-frames and cables (or other members) for pendulum, swing experiments, and for side on experiments.

15. Clamps and other attaching devices.

16. Other specialized equipment that may be needed will be specified (such as electro-hydraulic systems to apply dynamic forces to spring-mass system).

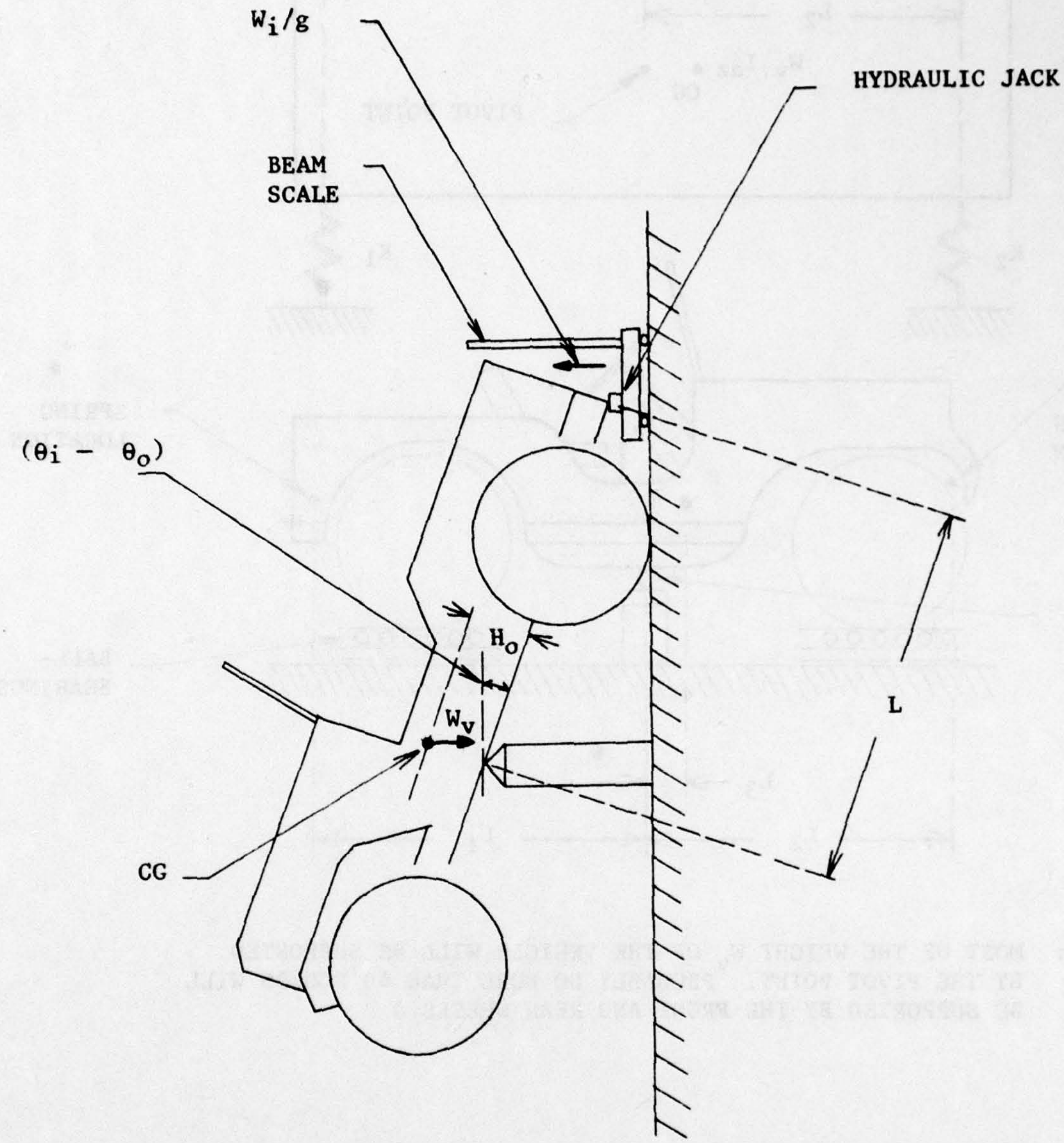
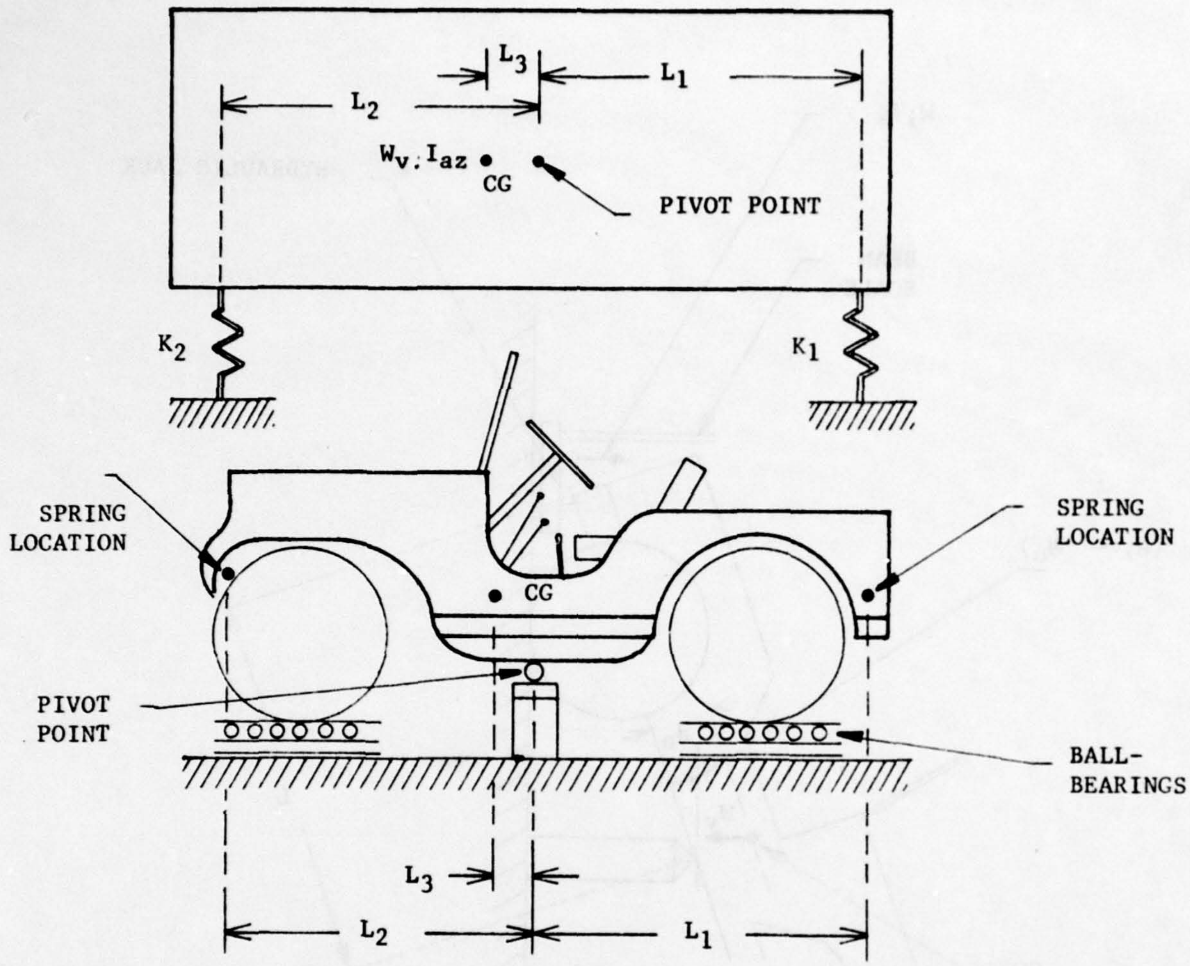


FIGURE 27. SCHEMATIC OF TEST CONFIGURATION FOR CG HEIGHT.



(NOTE: MOST OF THE WEIGHT W_v OF THE VEHICLE WILL BE SUPPORTED BY THE PIVOT POINT. PROBABLY NO MORE THAN 40 POUNDS WILL BE SUPPORTED BY THE FRONT AND REAR WHEELS.)

FIGURE 28: SCHEMATIC OF TEST CONFIGURATION FOR ROTATIONAL INERTIA ABOUT AZIMUTH

9.0 DETERMINATION OF STATIC AND DYNAMIC SUSPENSION (INCLUDING TIRES) CHARACTERISTIC OF VEHICLES

9.1 Force-Deflection of Static Suspension System

9.1.1 Determination of Total Force-Deflection Data for Combined Springs, Shock Absorbers, and Tires Suspension System

a. Placements of Weights

Certified weights will be placed over longitudinal and lateral axis of the vehicle's CG and,in general, right over the axles. This will give three loading positions.

b. Restriction on Suspension Systems

When loads are applied only on the rear suspension system, then the front system will be constrained by placing scissor jacks between the frame and the axle at the springs. Any shifting of load due to this constraint will be measured at the rear by load and deflection measuring devices. The rear suspension will be constrained similarly when loadings will be applied only to the front suspension system.

c. Points at which Deflections are Measured (Figure 29)

In general, measurements will be made at the following points:

i. Directly under each spring and at the axle;

ii. At the intersection of the frame or bumper and the lateral and longitudinal CG axis;

iii. At the center of bearing cap of each wheel;

iv. At several markings to be made on each tire. These markings will be used to measure local deflection of the tire relative to each other and to a horizontal (floor) reference plane. Also, the markings will be used for measuring load-deflection and load-velocity of the tire wall. The markings on the tires are to be made by a plumb line, i.e. a vertical plane;

v. Other points will be specified as required.

d. Data for Loading and Unloading Processes

The data for the load-deflection curve will be obtained for each increment of 50 lbs. weight added to the vehicle's weight and until the frame bottoms-out to the axle. The unloading portion of the curve will be obtained in the reverse process.

The average Coulomb friction (lbs.) will be one-half the weight difference between the loading and unloading curves. This coulomb friction would vary along the deflection (or loads) axis.

9.1.2 Force-Deflection of Tires Only

The suspension system will be completely restrained by four scissor jacks and the vehicle will be raised at the axles by a hydraulic jack to a position where the wheels are just off the ground. The jack will be placed on a scale and lowered at weight increments of 50 lbs., and deflection of each axle will be measured as well as the deflection of the markings on the tire at each of these increments. After the vehicle is not supported by the hydraulic jacks, then increments of 50 lbs. will be added up to 1000 lbs. or more. The vehicle will be unloaded by the same increments and the deflections will likewise be measured.

9.1.3 Force-Deflection of Spring and Shock Absorbing System

The vehicle will be raised and the axles placed on jack stands. The wheels will be removed. The vehicle will be raised on the longitudinal axis by a hydraulic jack placed on a scale and until all weight of the vehicle (less axle and spring) is off the springs. The jack will be lowered at increments of 50 lbs. (hence, loading the springs at increments of 50 lbs.) and until all of the vehicle's weight is on the springs. Increments of 50 lbs. will then be added to the vehicle until the frame bottoms-out to the axle (or until spring guard on frame touches the spring) . Unloading will proceed in the reverse manner. Deflections of the frame above springs will be recorded for each weight increase. The force-deflection measurements will be performed for: (1) totally unconstrained system; (2) only the front system constrained; and (3) only the rear system constrained.

9.1.4 Force-Deflection of Springs

The vehicle will stay in the same position, supported by jack stands at the axles without wheels, as in the previous paragraph. The shock absorbers will be detached. The test procedure will be the same as for the combined spring-shock absorber system.

9.1.5 Force-Deflection for Loading of One Side of the Vehicle

The test procedure will be the same as the loading of either front or rear of the vehicle except that the loading will be applied on one side of the vehicle. The vehicle should be raised to a sufficiently high level on one side, i.e. to a point where the vehicle would topple over onto its side. Some of the uncertainties that arise from this side on loading are the responses due to the torsions that are applied to the fore and aft suspension system of the side whose wheels are on the ground.

9.2 Force-Deflection and Force-Velocity of the Suspension System

The procedure for overall vehicle loading to determine the force-deflection and force-velocity data for the suspension system including the frame and the structural members of the vehicle could follow that presented previously. However, the loading could be applied in several other ways. These ways could include placing either electro-pneumatic or electro-hyraulic jacks or both between the vehicle and rigid frames (frames would be constructed and attached to the vehicle). Load gauges would have to be used in conjunction with deflection gauges. (Servo-accelerometers could be used to measure responses but are probably not sufficient to measure deflections.) The loads and the deflections' readings should be accomplished at the same points. By using several jacks one can apply various loads, such as side loads, etc., to qualitatively simulate the blast loadings. However, this would require further analysis.

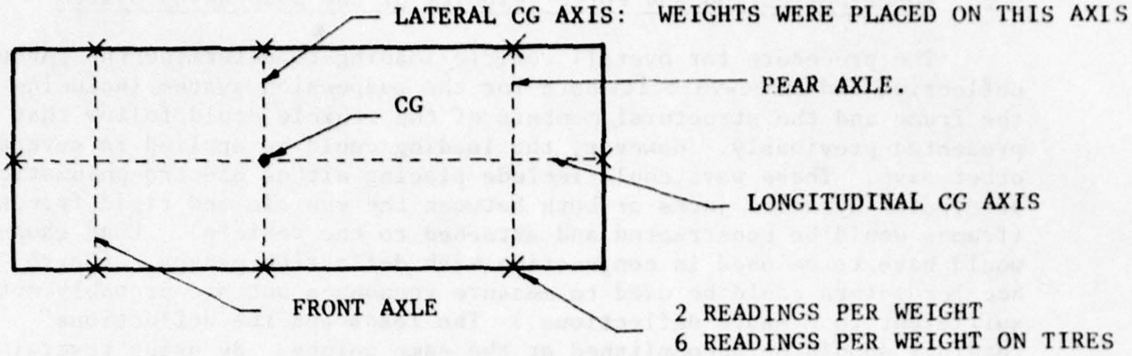


FIGURE 29a: TOP-VIEW OF WHERE READINGS WERE TAKEN AROUND THE SIDE OF THE VEHICLE

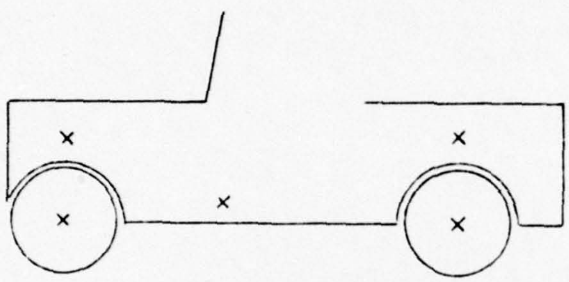


FIGURE 29b: LEFT-SIDE-VIEW OF WHERE READINGS WERE TAKEN

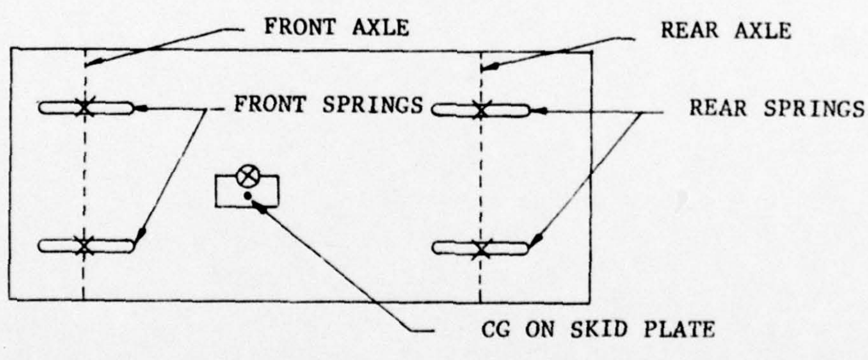


FIGURE 29c: BOTTOM-VIEW OF WHERE READINGS WERE TAKEN

FIGURE 29: LOCATIONS OF READINGS TAKEN ON M38A1 VEHICLES

(NOMENCLATURE: "X" Indicates where two readings were taken per increment of weight change.)

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